D180-29108-4

# ORBITAL TRANSFER VEHICLE

## CONCEPT DEFINITION AND SYSTEMS ANALYSIS STUDY

## FINAL REPORT – PHASE I
## VOLUME IV

## SPACE STATION ACCOMMODATIONS
## 1986

NASA/MSFC

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# CONCEPT DEFINITION

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Final Report

Volume IV

**SPACE STATION ACCOMMODATIONS**

D180-29108-4

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## FOREWORD

This final report of the Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Study was prepared by Boeing Aerospace Company for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-36107. The study was conducted under the direction of the NASA OTV Study Manager, Mr. Donald Saxton and during the period from August 1984 to September 1986.

This final report is organized into the following nine documents:

| | | |
|---|---|---|
| VOL. | I | Executive Summary (Rev. A) |
| VOL. | II | OTV Concept Definition & Evaluation |
| | | Book 1 - Mission Analysis & System Requirements |
| | | Book 2 - Selected OTV Concept Definition - Phase I |
| | | Book 3 - Configuration and Subsystem Trade Studies |
| | | Book 4 - Operations and Propellant Logistics |
| VOL. | III | System & Program Trades |
| VOL. | IV | Space Station Accommodations |
| VOL. | V | WBS & Dictionary |
| VOL. | VI | Cost Estimates |
| VOL. | VII | Integrated Technology Development Plan |
| VOL. | VIII | Environmental Analysis |
| VOL. | IX | Implications of Alternate Mission Models and Launch Vehicles |

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACC | Aft Cargo Carrier |
| AFE | Aeroassist Flight Experiment |
| AGE | Aerospace Ground Equipment |
| AL | Aluminum |
| ASE | Airborne Support Equipment |
| A/T | Acceptance Test, Auxiliary Tank |
| AUX | Auxiliary |
| AVG | Average |
| B/B | Ballute Brake |
| B/W | Backwall |
| CDR | Critical Design Review |
| CPU | Central Processing Unit |
| CUM | Cumulative |
| DAK | Double Aluminized Kapton |
| DDT&E | Design, Development, Test & Evaluation |
| DELIV | Delivery |
| DMU | Data Management Unit |
| DoD | Department of Defense |
| EPS | Electrical Power System |
| FACIL | Facility |
| FFC | First Flight Certification |
| FLTS | Flights |
| FOSR | Flexible Optical Surface Reflector |
| FRCI | Fiber Refractory Composite Insulation |
| F.S. | Fail Safe |
| FSI | Flexible Surface Insulation |
| FTA | Facilities Test Article |
| GB | Ground Based |
| GEO | Geostationary Earth Orbit |
| GPS | Global Positioning System |
| GRD | Ground |
| IOC | Initial Operational Capability |
| IRU | Inertial Reference Unit |
| IUS | Inertial Upper Stage |
| JSC | Johnson Space Center |

| | |
|---|---|
| L/B | Lifting Brake |
| LCC | Life Cycle Cost |
| L/D | Lift to Drag |
| MGSS | Mobile GEO Service Station |
| MLI | Multilayer Insulation |
| MPS | Main Propulsion System |
| MPTA | Main Propulsion Test Article |
| MSFC | Marshall Space Flight Center |
| OMV | Orbital Maneuvering Vehicle |
| OPS | Operations |
| OTV | Orbital Transfer Vehicle |
| PAM | Payload Assist Module, Propulsion Avionics Module |
| PDR | Preliminary Design Review |
| PFC | Preliminary Flight Certification |
| P/L | Payload |
| PROD | Production |
| PROP | Propellant |
| RCS | Reaction Control System |
| REF | Reference |
| RGB | Reusable Ground Based |
| R&R | Remove & Replace |
| RSB | Reusable Space Based |
| RSI | Reusable Surface Insulation |
| SB | Space Based |
| S/C | Spacecraft |
| SCB | Shuttle Cargo Bay |
| SIL | Systems Integration Laboratory |
| STA | Structural Test Article |
| STG | Stage |
| STS | Space Transportation System |
| T/D | Turndown |
| TDRS | Tracking Data Relay Satellite |
| TPS | Thermal Protection System |
| TT&C | Telemetry, Tracking and Control |
| WBS | Work Breakdown Structure |

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# 1.0 INTRODUCTION

This section provides a description of the study in terms of background, objectives, issues, organization of study and report, and the content of this specific volume.

Use of trade names, names of manufacturers, or recommendations in this report does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

And finally, it should be recognized that this study was conducted prior to the STS safety review that resulted in an STS position of "no Centaur in Shuttle" and subsequently an indication of no plans to accommodate a cryo OTV or OTV propellant dump/vent. The implications of this decision are briefly addressed in section 2.2 of the Volume I and also in Volume IX reporting the Phase II effort which had the OTV launched by an unmanned cargo launch vehicle. A full assessment of a safety compatible cryo OTV launched by the Shuttle will require analysis in a future study.

## 1.1 BACKGROUND

Access to GEO and earth escape capability is currently achieved through the use of partially reusable and expendable launch systems and expendable upper stages. Projected mission requirements beyond the mid-1990's indicate durations and payload characteristics in terms of mass and nature (manned missions) that will exceed the capabilities of the existing upper stage fleet. Equally important as the physical shortfalls is the relatively high cost to the payload. Based on STS launch and existing upper stages, the cost of delivering payloads to GEO range from $12,000 to $24,000 per pound.

A significant step in overcoming the above factors would be the development of a new highly efficient upper stage. Numerous studies (ref. 1, 2, 3, 4) have been conducted during the past decade concerning the definition of such a stage and its program. The scope of these investigations have included a wide variety of system-level issues dealing with reusability, the type of propulsion to be used, benefits of aeroassist, ground- and space-basing, and impact of the launch system.

## 1.2 OBJECTIVES AND ISSUES

The overall objective of this study was to re-examine many of these same issues but within the framework of the most recent projections in technology readiness, realization that a space station is a firm national commitment, and a refinement in mission projections out to 2010.

During the nineteen-month technical effort the specific issues addressed were:

a. What are the driving missions?

b. What are the preferred space-based OTV characteristics in terms of propulsion, aeroassist, staging, and operability features?

c. What are the preferred ground-based OTV characteristics in terms of delivery mode, aeroassist, and ability to satisfy the most demanding missions?

d. How extensive are the orbital support systems in terms of propellant logistics and space station accommodations?

e. Where should the OTV be based?

f. How cost effective is a reusable OTV program?

g. What are the implications of using advanced launch vehicles?

## 1.3 STUDY AND REPORT ORGANIZATION

Accomplishment of the objectives and investigation of the issues was done considering two basic combinations of mission models and launch systems. Phase I concerned itself with a mission model having 145 OTV flights during the 1995-2010 timeframe (Revision 8 OTV mission model) and relied solely on the Space Shuttle for launching. Phase 2 considered a more ambitious model (Rev. 9) having 442 flights during the same time frame as well as use of a large unmanned cargo launch vehicle and an advanced Space Shuttle (STS II).

The study is reported in nine separate volumes. Volume I presents an overview of the results and findings for the entire study. Volume II through VIII contains material associated only with the Phase I activity. Volume IX presents material unique to the Phase II activity. Phase I involved five quarters of the technical effort and one quarter was associated with the Phase II analyses.

## 1.4 DOCUMENT CONTENT

This specific document reports the work associated with the hardware and physical integration aspects of OTV accommodations at a space station, a summary of the OTV imposed requirements and finally a discussion of the key issues associated with the accommodation of an OTV at a space station. OTV processing operations occurring at the station are reported in Volume II, Book 4.

# 2.0 OTV ACCOMMODATIONS OVERVIEW

This section presents an overview of the objectives, emphasis, groundrules and assumptions associated with the space station accommodations activity. It will be noted that this effort was performed during a timeframe when the NASA space station design was referred to as "Power Tower" rather than a later version called "Dual Keel". In the judgement of the Boeing OTV study team, we would expect no major change in our findings should the Dual Keel concept have been used in the analysis.

## 2.1 OBJECTIVE AND EMPHASIS

The primary objective of the Space Station Accommodations Concept Definition task (Task 5) was to define Space Station accommodations and assess the requirements on the space Station for hardware elements, resources, and interfaces necessary to support a reusable Orbit Transfer Vehicle (OTV). Our emphasis within this objective was to develop data that allowed discrimination among the space based concepts and between space and ground based OTV's.

## 2.2 REQUIREMENTS, GROUNDRULES, AND ASSUMPTIONS

The overall operations flow for a space-based OTV is presented in figure 2.2-1. Support requirements and hardware elements or accommodations resulting from the top level flow are shown in figure 2.2-2. Most significant of the OTV accommodations is 1) a hangar to provide meteoroid/debris protection, storage, and maintenance shelter and 2) a fluid management facility to enable refueling.

The key groundrules and assumptions associated with the OTV/station accommodations activity are shown in table 2.2-1. OTV IOC's, Space Shuttle characteristics and crew cost were provided by NASA. Our analysis of the NASA provided mission model (see Volume II, Book 1) resulted in the indicated amount of time between the completion of a given type of mission and initiation of another mission. To these we added the transit times and turnaround times to develop cycle times for an OTV and eventually the definition of amount of accommodations required to support the OTV fleet. We also assumed that GEO platforms are moved about on the Space Station folded up, and only deployed after being attached to the OTV. This reduced MRMS length and moment of inertia requirements.

The starting point Space Station configuration used to perform the OTV/station accommodations analysis is shown in figure 2.2-3. This concept defined by NASA as the Full Operating Capability (FOC) Space Station is assumed to be operational by 1997. Again, the Dual Keel concept occurred late in the study but would not have changed the findings and key considerations.

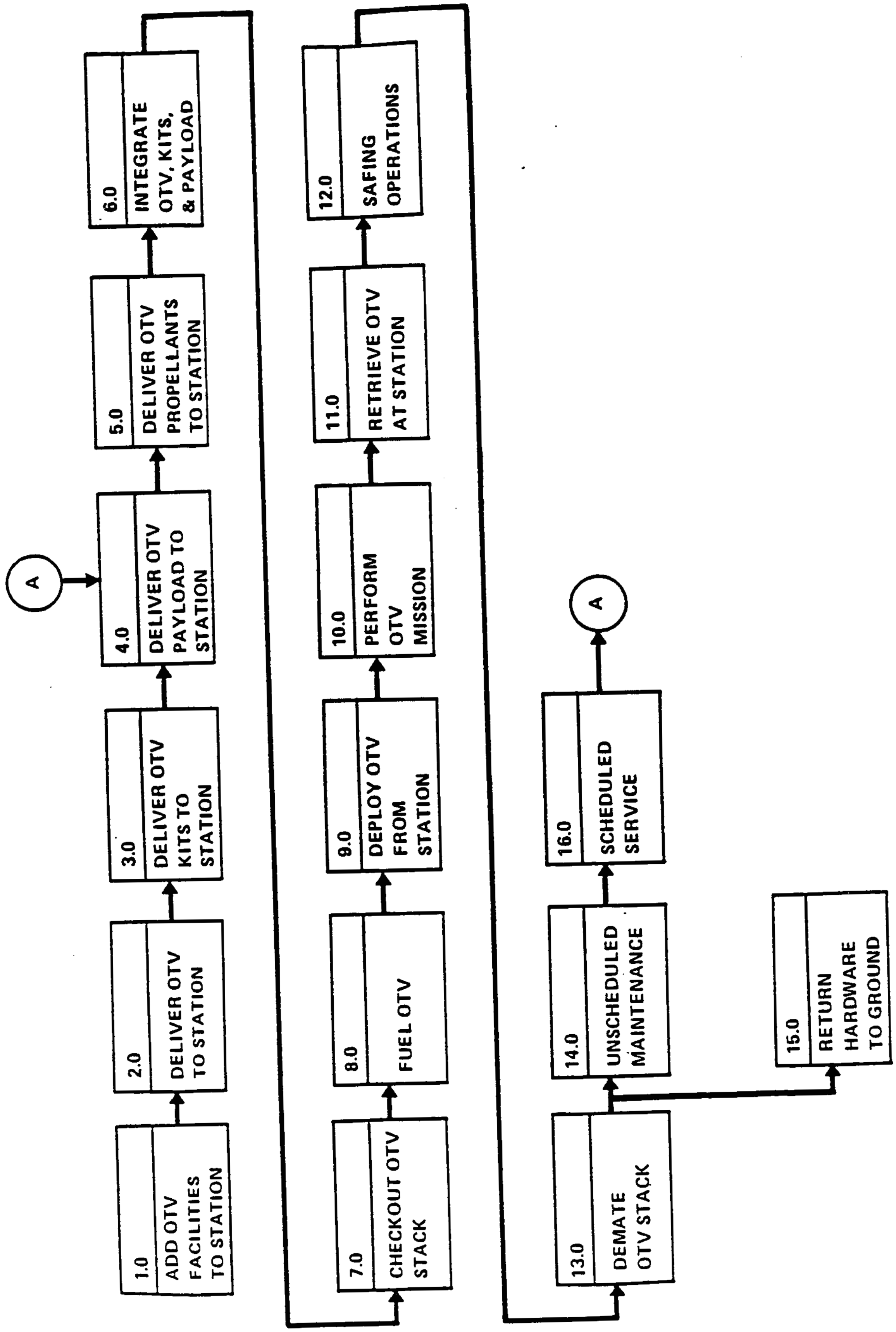
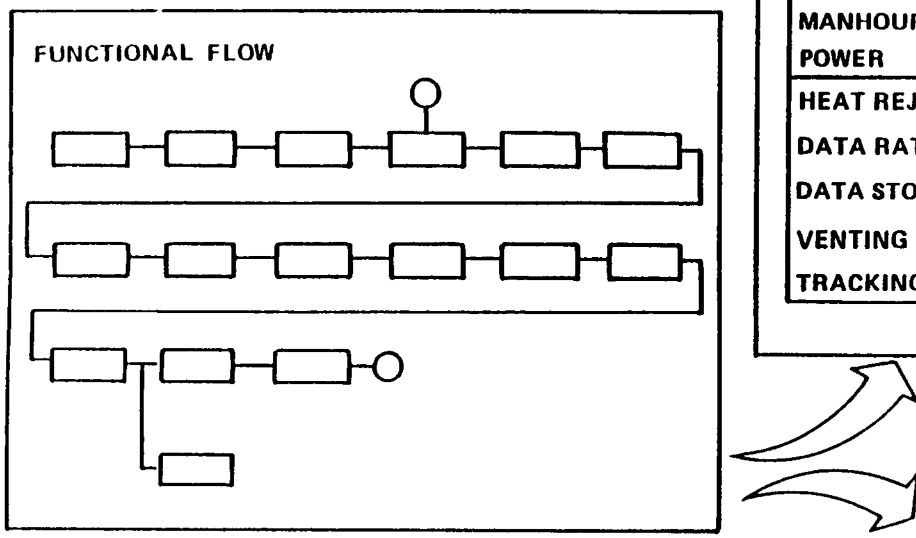



*Figure 2.2-1 Station Flight Operations*




**REQUIREMENTS DERIVATION**

| STATION REQUIREMENT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STORAGE VOLUME | | | ● | ● | ● | ● | ● | ● | | | | ● | ● | | | |
| ENCLOSED VOLUME | | ● | | | | | | | | | | | | ● | | ● |
| PRESSURIZED VOLUME | | | | | | | | | | | | | | ● | | ● |
| MANHOURS | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● |
| POWER | | | | | | ● | ● | | ● | | ● | | ● | ● | | ● |
| HEAT REJECTION | | | | | | ● | ● | ● | | | | ● | ● | ● | | ● |
| DATA RATE | | | | | | | ● | | ● | | ● | | | | | |
| DATA STORAGE | | | | | | | ● | | | | | | | | | |
| VENTING | | | | | ● | | | ● | | | | ● | | | | |
| TRACKING | | | | | | | | | ● | | ● | | | | | |

(Column headings 1–16: OPERATIONS TASKS)

**FUNCTIONAL ALLOCATION**

| HARDWARE ELEMENT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IOC STATION | ● | | ● | ● | | | | | | | | | | | ● | |
| HANGAR | | ● | | | | | | | | | | | | ● | | ● |
| FLUID MGMT | | | | | ● | | | ● | | | | ● | | | | |
| $OTV_{SUPPORT}$ | | | | | | ● | | | | | | | ● | | | |
| PRESS. MOD. | | | | | | | ● | | | | | | | | | |
| LAUNCH & RETR | | | | | | | | | ● | | ● | | | | | |

(Column headings 1–16: OPERATIONS TASKS)

*Figure 2.2-2 Space Station Flight Operations Analysis*

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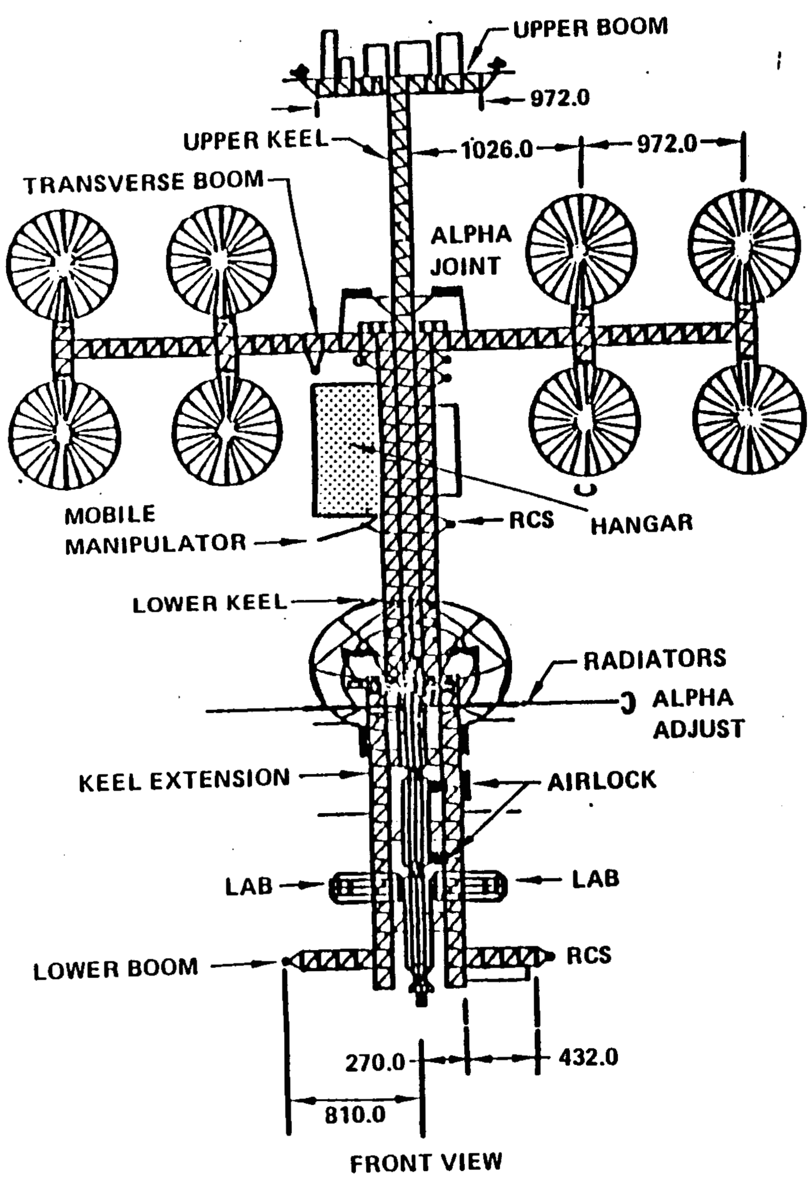
*Table 2.2-1 Groundrules and Assumptions*

- OTV IOC—1994
  SPACE BASED – 1997
- TIME UNTIL NEXT FLIGHT AFTER PERFORMING AN:

| | DAYS |
|---|---|
| UNMANNED GEO DELIVERY | 13 |
| UNMANNED GEO SERVICING DEMO | 22 |
| MANNED GEO SORTIE | 30 |
| DoD | 13 |
| MANNED LUNAR SORTIE – UPPER STAGE | 33 |
| – LOWER STAGE(S) | 13 |
| UNMANNED LUNAR DELIVERY—UPPER STAGE | 29 |
| —LOWER STAGE | 13 |
| PLANETARY | 16 |
| REFLIGHT | 20 |

- GEO PLATFORMS MOVED ON STATION FOLDED UP, DEPLOYED ON OTV PRIOR TO LAUNCH (EXCEPT FOR MAIN SOLAR ARRAYS)
- SHUTTLE PERFORMANCE AT ALTITUDE h(nmi) = 87,960 – 114h
  COST PER FLIGHT $73.0M (LOW MODEL)
  $63.7M (NOM. MODEL)
- SPACE STATION CREW COSTS
  1 MANHOUR IVA – $ 16,000
  1 MANHOUR EVA – $48,000
  1 EVA HOUR (2 OUTSIDE CREW, 1 INSIDE) – $112,000




REQUIREMENTS:

- PROVIDE SPACE FOR OTV FACILITIES, HARDWARE, AND OPERATIONS
  - EXTERIOR STORAGE VOLUME
  - STRUCTURAL SUPPORT
- PROVIDE SERVICE AND MAINTENANCE MANHOURS
- PROVIDE POWER IF NECESSARY
- PROVIDE TRACKING AND CONTROL FOR DEPLOYMENT AND RECOVERY

*Figure 2.2-3 FOC Station*

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# 3.0 HARDWARE DEFINITION

This section defines the major hardware elements which constitute the OTV accommodations required at a space station. The most significant items include hangar, propellant storage and transfer system, servicing and handling equipment and pressurized modules.

## 3.1 HANGAR

### 3.1.1 Requirements and Assumptions

The hangar has the functional requirements of 1) providing protection against meteoroids and space debris when the OTV is at the station, and 2) serving as a shelter when maintenance is performed on the OTV.

The overall size of the hangar must be sufficient to accommodate the OTV itself, house the servicing equipment and spares, and have adequate clearance to allow EVA activity associated with OTV assembly and/or servicing. The values assumed for the above factors are shown in table 3.1-1. It will also be noted the overall size takes into account allowances for the volume required for servicing and handling equipment (defined in section 3.3) and for the thickness of the hangar wall.

Table 3.1-1 Hangar Sizing Factors

| | |
|---|---|
| o OTV Sizes (ft.) | |
| o Ballute Brake OTV | 15D X 38L |
| o Lifting Brake OTV | 42D X 23L |
| o Shaped Brake OTV | 36 X 44 X 16 |
| o Clearances | |
| o Separating Hardware Elements | 1 ft |
| o EVA Mobility | 4 ft |
| o Allowances | |
| o Servicing equip and spares | 1 ft |
| o Wall thickness | 1 ft |

### 3.1.2 Trades

#### 3.1.2.1 Internal Versus External OTV Servicing

Prior studies (Reference 3) have indicated the use of a hangar for OTV servicing. As indicated in the requirements section this does increase the size of the hangar and thus its cost as well as additional drag and orbit make-up propellant. An alternative is to size the hangar only for storage and provide protection against meteoroids/debris. The OTV would then be moved outside for servicing resulting in a smaller hangar.

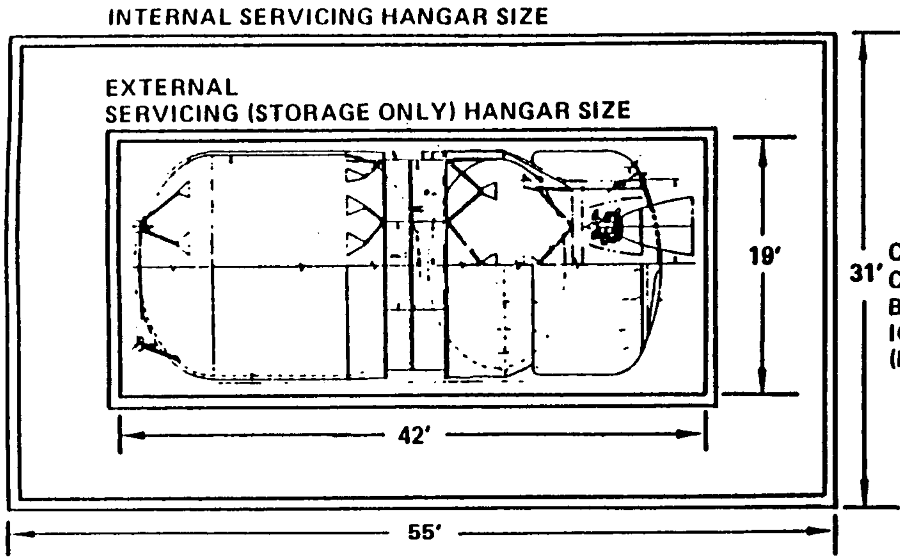
The results of the trade between servicing inside and outside the hangar for a ballute braked OTV is presented in figure 3.1-1. As indicated by the cost comparison curves, the servicing inside the hangar approach becomes cheaper after the second year. This conclusion is based on the following. The DDT&E, production, and delivery cost difference between the hangars is estimated at $4152/lb. The hangar walls average 0.74 lb/sq. ft. The acquisition and delivery difference between the hangar sizes is then $11.15 million. The larger hangar incurs a cost penalty of $455,000 per year for added drag makeup propellant due to its larger cross section. The outside servicing option requires set-up time that is not needed inside a hangar. When working outdoors, lighting and other factors make the work pace slower. These add 6 hours of EVA to each mission, which amounts to $5.376 million per year for the low mission model.

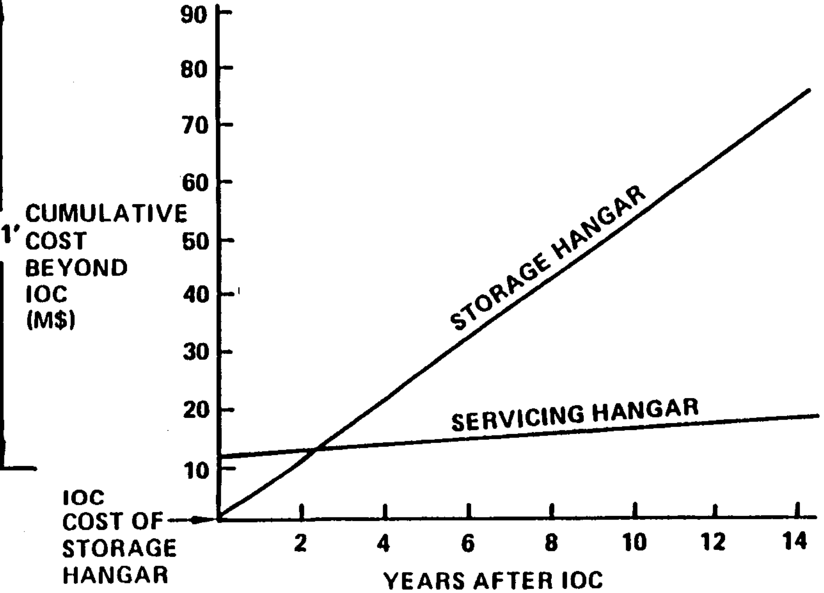
#### 3.1.2.2 Hangar Packaging Trade

Two hangar packaging concepts shown in figure 3.1-2 were evaluated for their impact on delivery and installation cost. Concept "A" requires the minimum amount of on-orbit assembly. The Shuttle payload is a single deployable structure that unfolds to become one half of the hangar. Two launches are required to deliver the hangar plus 0.1 flights to deliver the door.

Concept "B" divides the hangar into a large number of small deployable sections. These require only 0.7 of a launch to deliver the hangar structure.

A number of factors affect the number of parts associated with the hangar. The amount of on-orbit assembly time per part, the efficiency in fitting the sections in the shuttle, and the cost of a shuttle launch all play a part. When looked at in terms of how many typical sections (or parts) will fill a Shuttle flight, the optimum number of parts is a function of the assembly time. The relationship between installed cost and numbers of parts is presented in figure 3.1-3. For a payload that takes 10 hours per section for assembly, such as the OTV vehicle, the optimum is about six sections. For a simpler structure such as the hangar walls, which take one hour per part, the optimum is 60 sections which is concept B, minimum cargo volume.




INTERNAL SERVICING HANGAR

- ADDED COSTS OF LARGER HANGAR:
  - AREA $502/FT$^2$/YEAR X 907 FT$^2$ DELTA = $0.455 MILLION/YEAR
  - WEIGHT $4152/LB X 0.74 LB/FT$^2$ X 907 FT$^2$ X 4 WALLS = $11.15 MILLION

EXTERNAL SERVICING HANGAR

- SERVICING EVA TIME INSIDE SERVICING HANGAR = 22 HRS X [2 EVA CREW + 1 IVA CREW]
- EVA COSTS $112K/HR
- DELTA EVA TIME FOR STORAGE ONLY HANGAR:
  - TOOL SET-UP/TEAR-DOWN AT WORK LOCATION – 2 HRS
  - SLOWER WORK PACE DUE TO LIGHTING CONDITIONS AND TOOL USE – 4 HRS

TOTAL DELTA/OTV MISSION 6 HRS

- SERVICING HANGAR

  $11.15 MILLION FOR LARGER HANGAR + 0.455 MILLION/YEAR FOR DRAG

- STORAGE HANGAR

  $112/HR X 6 HR/FLIGHT EXTRA EVA X 8 FLIGHTS/YEAR = $5.376 MILLION/YEAR

*Figure 3.1-1 Internal Versus External OTV Servicing*

OTV-679

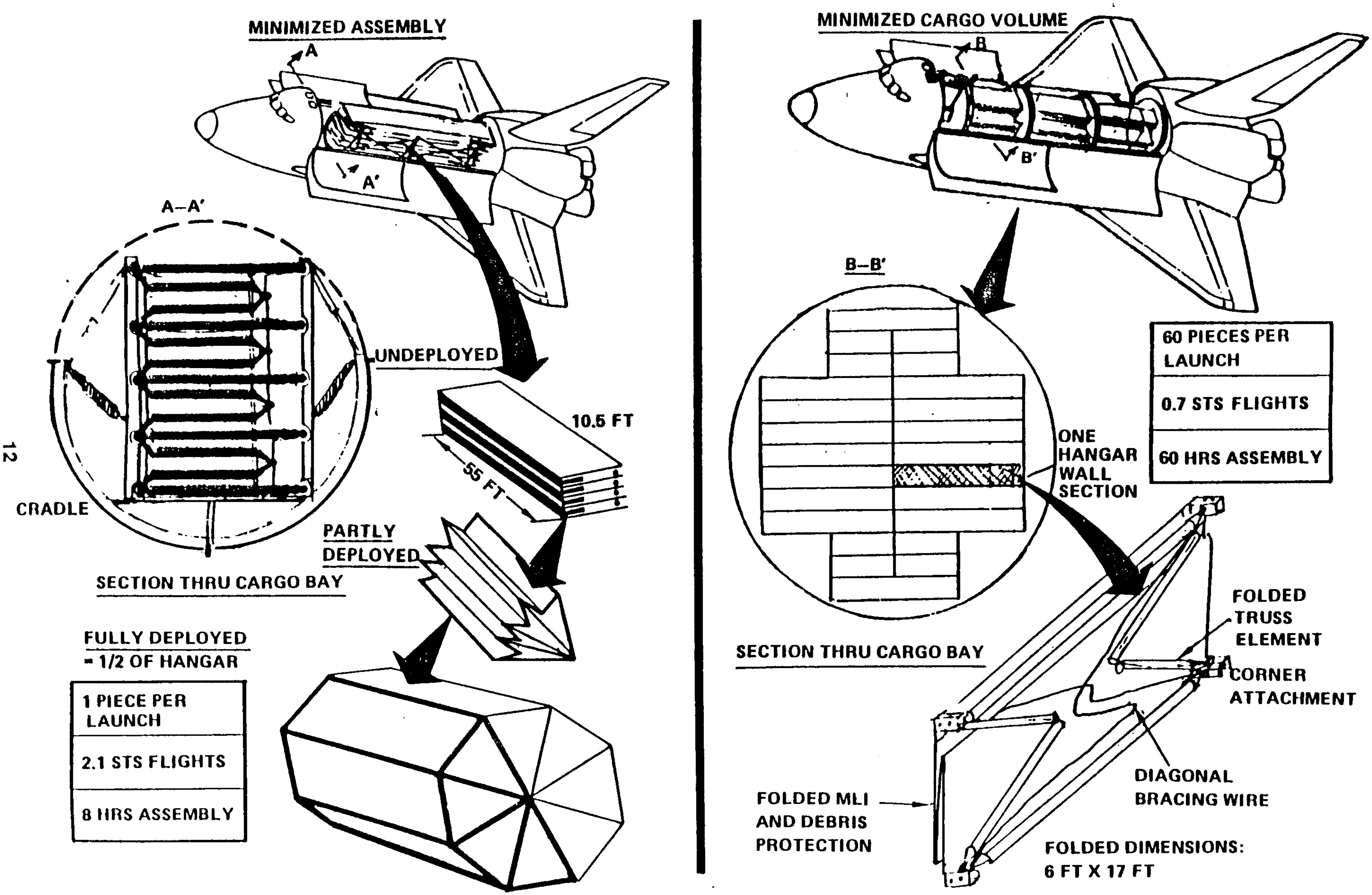
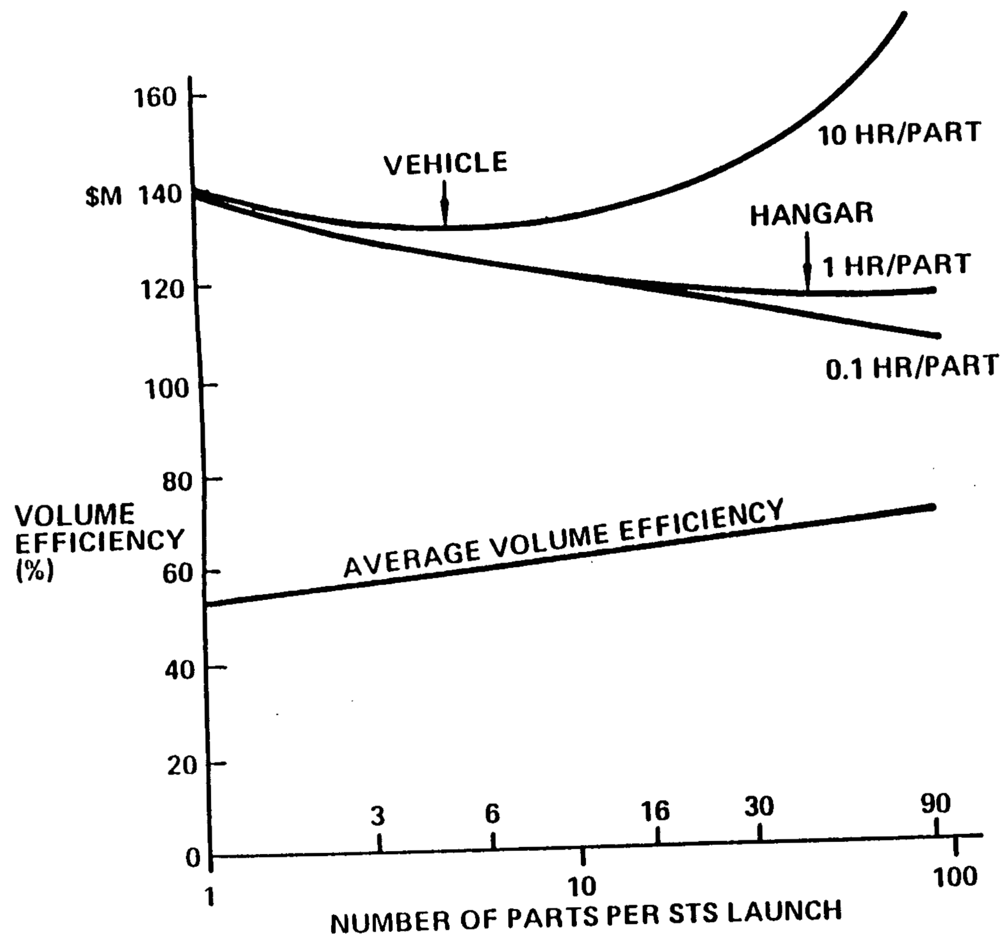



*Figure 3.1-2 Hangar Packaging Concepts*



700




QUESTION: WHAT IS THE MOST EFFICIENT PACKAGING FOR DELIVERY TO ORBIT OF AEROBRAKE, HANGAR, AND PROPELLANT STORAGE SYSTEM.

ASSUMPTIONS:

$ 73M PER LAUNCH

$112K PER EVA—HOUR

10 HOURS PER ITEM ASSEMBLY/ ERECTION TIME FOR VEHICLE

RESULTS

- OPTIMUM IS ABOUT 6 PIECES/LAUNCH FOR VEHICLE @ 10 HRS/PART
- 60 PC/LAUNCH FOR HANGAR @ 1 HR/PART ASSEMBLY/ERECTION TIME

*Figure 3.1-3 Packaging Trade Figure*

OTV-769

### 3.1.2.3 Meteoroid and Debris Protection Trade

The wall of the hangar will perform several functions: thermal protection, light dispersion, tool and spares storage, and meteoroid and debris protection. Variation in wall design regarding meteoroid/debris protection were investigated for their impact on system level cost considering hangar cost and OTV repair cost. Hangar walls ranging from 30 layers of multi-layer insulation (MLI) to nearly 0.08 inch thick aluminum were investigated with the comparison presented in table 3.1-2. As the wall gets thicker and has more mass the probability of damage to an OTV from space debris is reduced, but the cost of the hangar increases. This data indicates that the least cost occurs when the wall consist of 30 layers of MLI which is also adequate for thermal protection.

### 3.1.3 Design Concepts

This section describes the features that are common to hangars for any SB or GB OTV and the internal arrangement concept for each SB OTV hangar.

### 3.1.3.1 Common Features

Features that are common to all hangars include the construction concept and wall design characteristics. The construction concept is shown in figure 3.1-4 and reflects the packaging concept selected in section 3.1.2. Each hangar section contains two collapsed truss elements which are unfolded and locked into place. The hangar section is bolted to the adjacent section at its corner. The sections attached to the Station will have additional attachment points, and openings in the MLI to allow wiring to be installed later. The hangar doors, lights, and internal equipment are installed later.

Figure 3.1-5 shows a typical panel section for the space based OTV hangar. The 12x17 ft size is the largest that can be accommodated with this construction concept because of the need to fit in the Shuttle cargo bay when folded. The weight of this section is 139 lbs including a 15% growth allowance. It should be noted, however, all sections of a hangar are not the same size due to the dimensions of the hangar. Total hangar weights for the various space and ground based OTV configurations is presented in table 3.1-3. The variation in the hangar weights is due to the differences in the size of the hangars, due to the differences in vehicle or auxiliary tank sizes. Note that these estimates are for the hangar only, and does not include any internal equipment.

Table 3.1-2. Hangar Wall Design Comparison

| Hangar wall type | Wall thickness $t_s$ (in) | Wall weight (lb) | Wall cost (M$) | Probability of no penetration $P_o$ | OTV repair cost (M$) | Total cost (M$) |
|---|---|---|---|---|---|---|
| • 30 layers MLI | .0026 | 375 | 1.55 | .9547 | 3.17 | 4.73 |
| • 60 layers MLI | .0052 | 750 | 3.12 | .9725 | 1.92 | 5.04 |
| • 90 layers MLI | .0078 | 1,125 | 4.67 | .9784 | 1.44 | 6.11 |
| • .016 Aluminum sheet + 30 layers MLI | .0186 | 2,684 | 11.15 | .9886 | 0.80 | 11.94 |
| • .0374 Aluminum sheet + 30 layers MLI | .04 | 5,771 | 23.96 | .9924 | 0.53 | 24.49 |
| • .0774 Aluminum sheet + 30 layers MLI | .08 | 11,543 | 47.93 | .9935 | 0.45 | 48.38 |

Assumptions:

- OTV repair cost = $70 million (repair and relaunch)
- Hangar cost = $2,800/lb development and production + $1,352/lb delivery = $4,125/lb
- Hangar size = 10,020 $ft^2$
- Vehicle section = 1,200 $ft^2$
- Vehicle to hangar spacing = 6 ft
- Exposure = 10 years

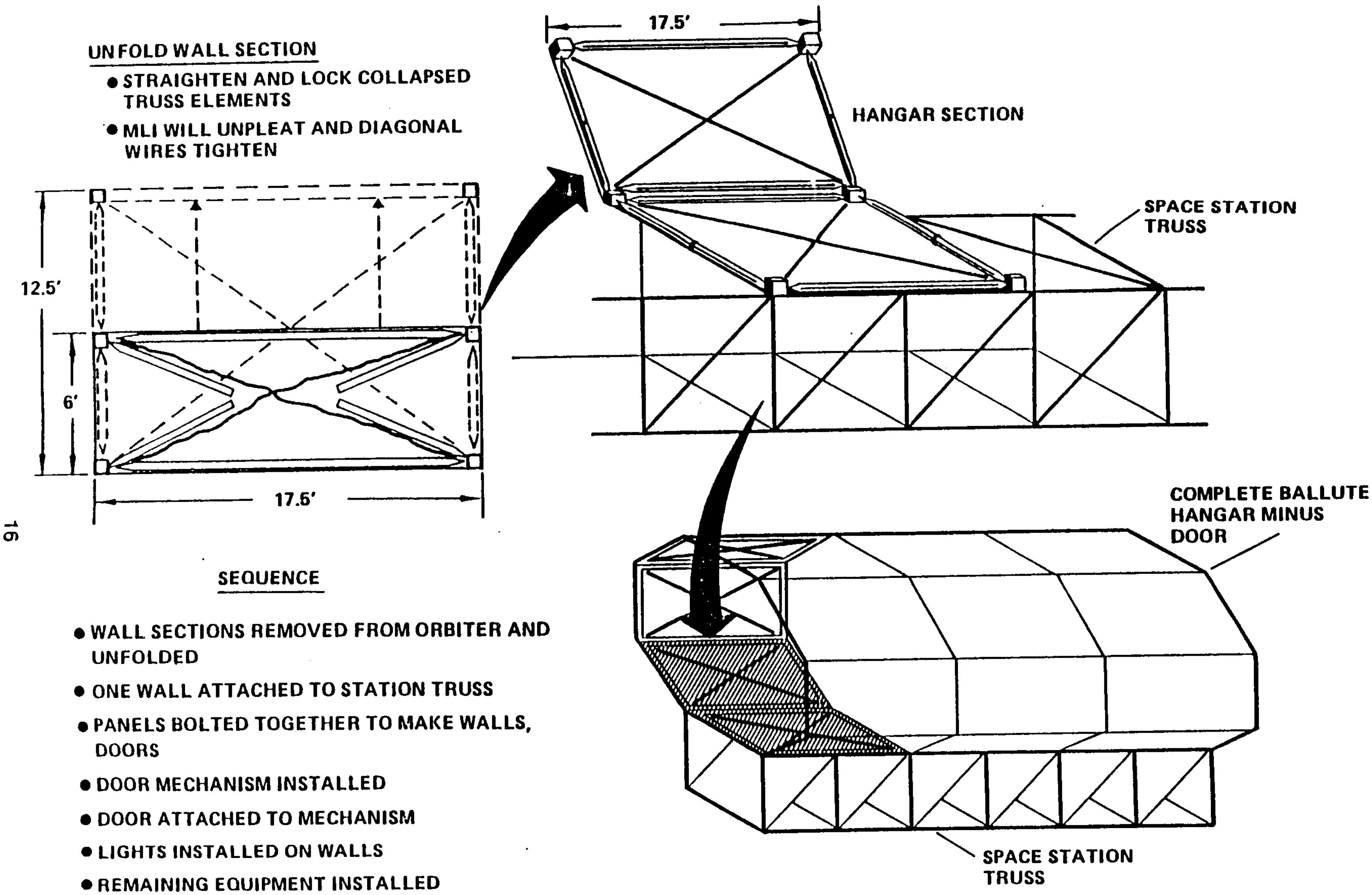



*Figure 3.1-4 Hangar Construction Concept*

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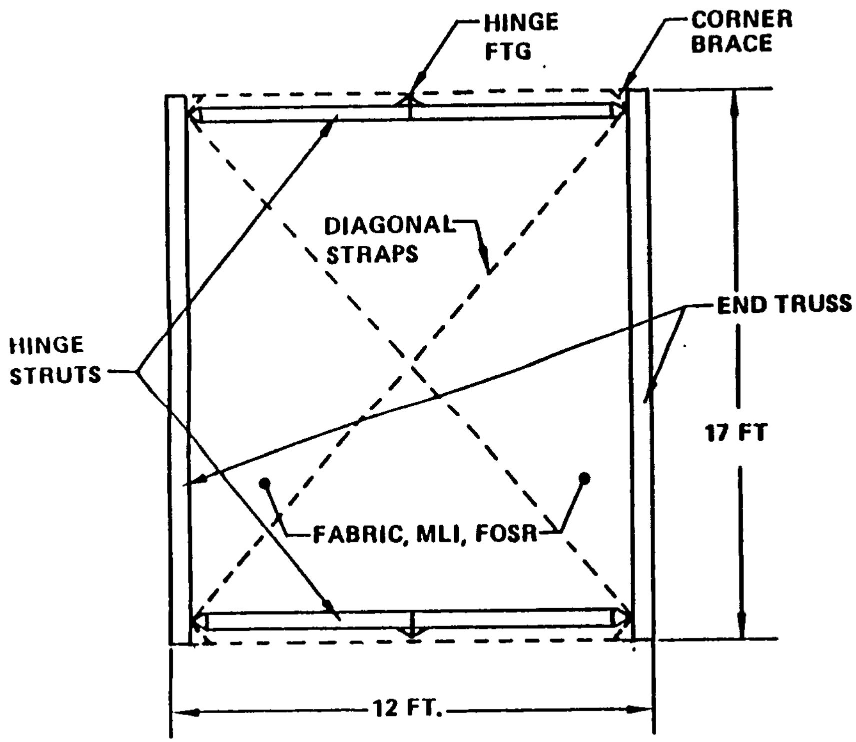


| ITEM | WEIGHTS–TYP. (LB.) | |
|---|---|---|
| PRIMARY STRUCTURE | | (70) |
| CORNER BRACE (4) | 8 | |
| END TRUSS (2) | 30 | |
| HINGE STRUTS (2) | 10 | |
| HINGE FTGS(2) | 4 | |
| END FTGS (4) | 8 | |
| MISCELLANEOUS | 10 | |
| SECONDARY STRUCTURE | | (12) |
| KEVLAR FABRIC | 4 | |
| CONSTRUCTION ALLOWANCE | 2 | |
| ATTACHMENT ALLOWANCE | 6 | |
| THERMAL CONTROL | | (39) |
| MLI, INC. CONSTRUCTION | 25 | |
| FOSR | 14 | |
| WEIGHT GROWTH | | (18) |
| (TOTAL) | | (139) |

*Figure 3.1-5 Wall/Door Typical Panel Section (12 Ft. x 17 Ft.)*

Table 3.1-3 Hangar Component Weights

| HANGAR TYPE | MAST ATTACH MECHANISMS | | DOOR MECHANISMS | | WALL/DOOR [1] PANEL SECTIONS | | TOTAL WEIGHT * |
|---|---|---|---|---|---|---|---|
| | NO. | WEIGHT | NO. | WEIGHT | NO. | WEIGHT | |
| RECOVERABLE AUX. TANKS | 4 | 230 | 8 | 230 | 18 | 1651 | 2111 |
| EXPEND. AUX. TANKS | 4 | 230 | 8 | 230 | 18 | 1715 | 2175 |
| BALLUTE-BRAKED OTV | 4 | 230 | 8 | 230 | 42 | 4779 | 5239 |
| SHAPE-BRAKE OTV | 4 | 230 | 8 | 230 | 72 | 8519 | 8979 |
| LIFTING BRAKE OTV | 4 | 230 | 8 | 230 | 60 | 6764 | 7224 |

[1] SIZE OF INDIVIDUAL PANEL SECTIONS DEPENDENT ON CONFIGURATION

*DOES NOT INCLUDE INTERNAL EQUIPMENT

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### 3.1.3.2 Internal Arrangement

**Ballute OTV Hangar**

The Ballute OTV hangar is shown figure 3.1-6. The most significant task to be performed in the hangar is attaching a new ballute to the OTV, after each flight. In order to conserve space, ballutes are stored on the hangar door. Attachment of a ballute begins by attaching the ballute installation fixture to the ballute. Next the hangar door is opened to detach the ballute from its support stand. The ballute is rotated 180 degrees and placed over the end of the vehicle. The hangar door is then closed. The OTV is attached to a support stand in the hangar. The support stand attaches to the OTV payload interface and is connected to the Space Station truss. The Station provides electrical power, health, and commands via a cable tray run from the Station truss through the stand and to the vehicle. The hangar has tracks on which run mobile robots, which are small versions of the Station MRMS. Various handling fixtures and tools can be affixed to the robot to aid in servicing operations, such as an engine removal tool, or an astronaut foot restraint/control console. Orbital replaceable units and tools are stored on the walls of the hangar. The mobile robots can reach anywhere in the hangar.

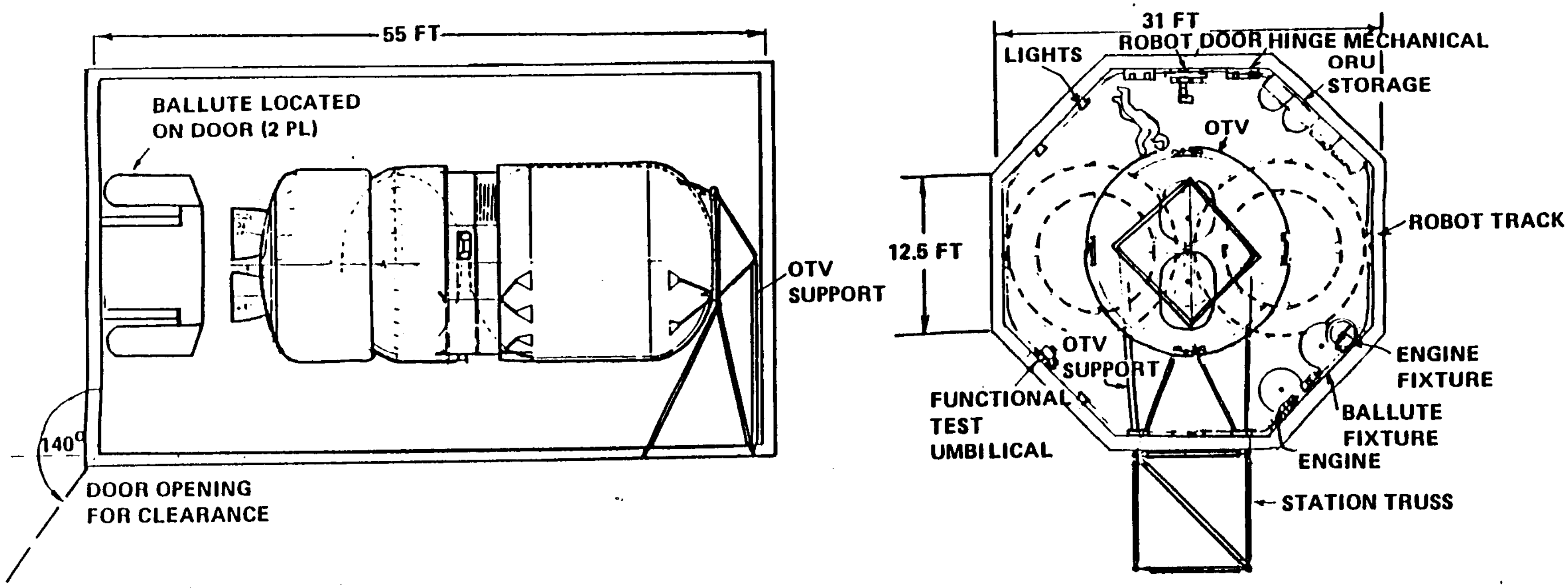
The Ballute OTV hangar walls are shown 'unrolled' in figure 3.1-7 to more clearly depict the location of the support equipment. Mobile robot tracks run longitudinally on four sides and circumferentially in two places to allow access to all parts of the hangar.

**Lifting Brake OTV Hangar**

The lifting brake OTV hangar shown in figure 3.1-8 is sized by the space required for removal and replacement of a main engine which also requires removal of the brake. Because of the larger diameter of the vehicle, the mobile robots require a reach length of about 25 feet. Mobile robot joints are designed to allow removal of an engine without damaging the brake. The brake is held by a fixture that uses the engine door frame as the attachment point. Access to the hangar by EVA astronauts is through an airlock in the pressurized module, which connects directly with the hangar interior.

**Shaped Brake OTV Hangar**

The shaped braked OTV consist of large sections which must be assembled on orbit. Storage of these sections prior to assembly results in this hangar being larger then hangers for the other OTV's. The arrangement of the shaped brake OTV hangar is presented in figure 3.1-9.




NOTE: ASTRONAUT FOR SCALE ONLY

*Figure 3.1-6 Interior Arrangement — Ballute OTV Hangar*

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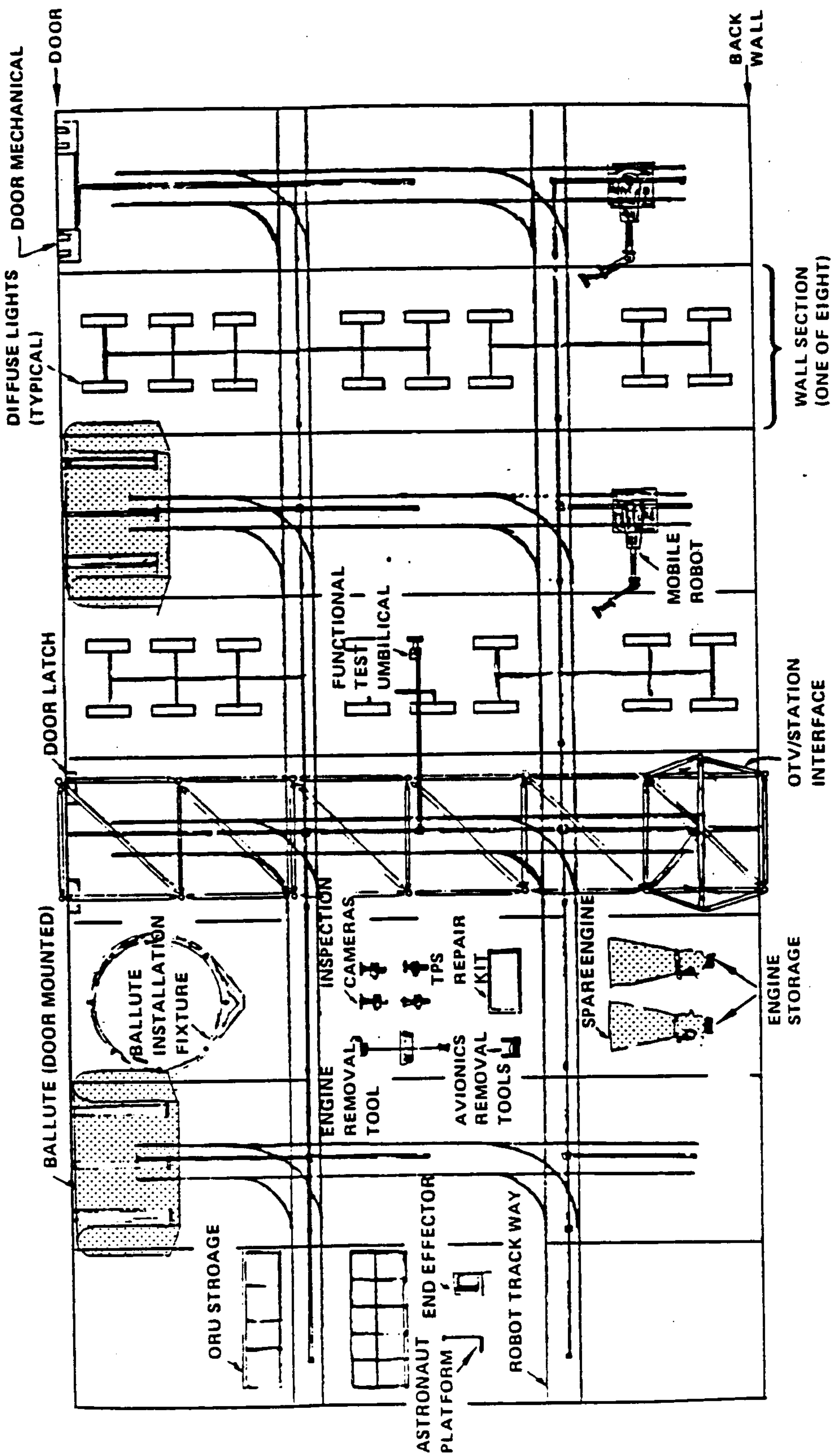


*Figure 3.1-7 Interior Arrangement — Ballute OTV Hangar*

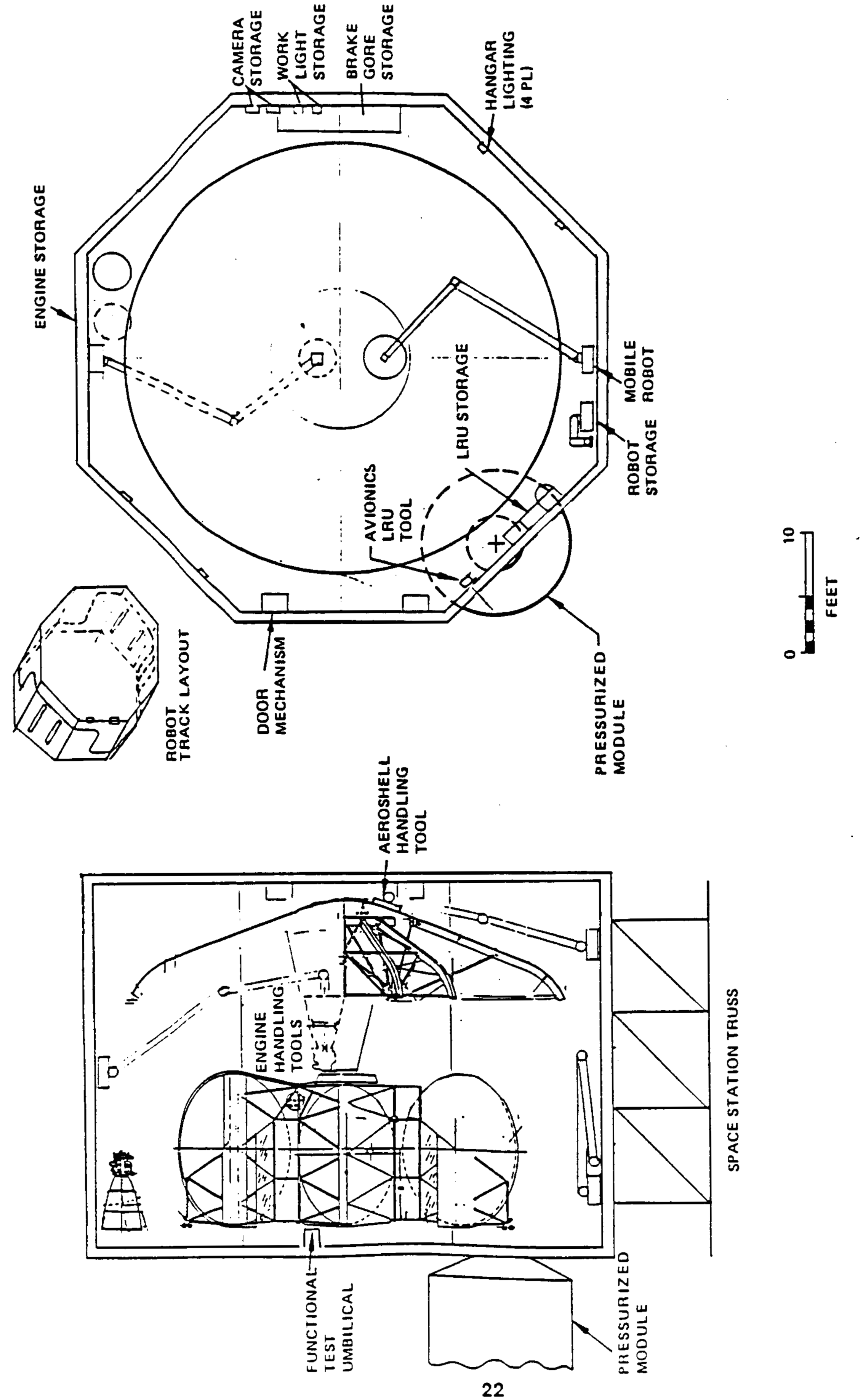


*Figure 3.1-8 Interior Arrangement – Lifting Brake OTV Hangar*

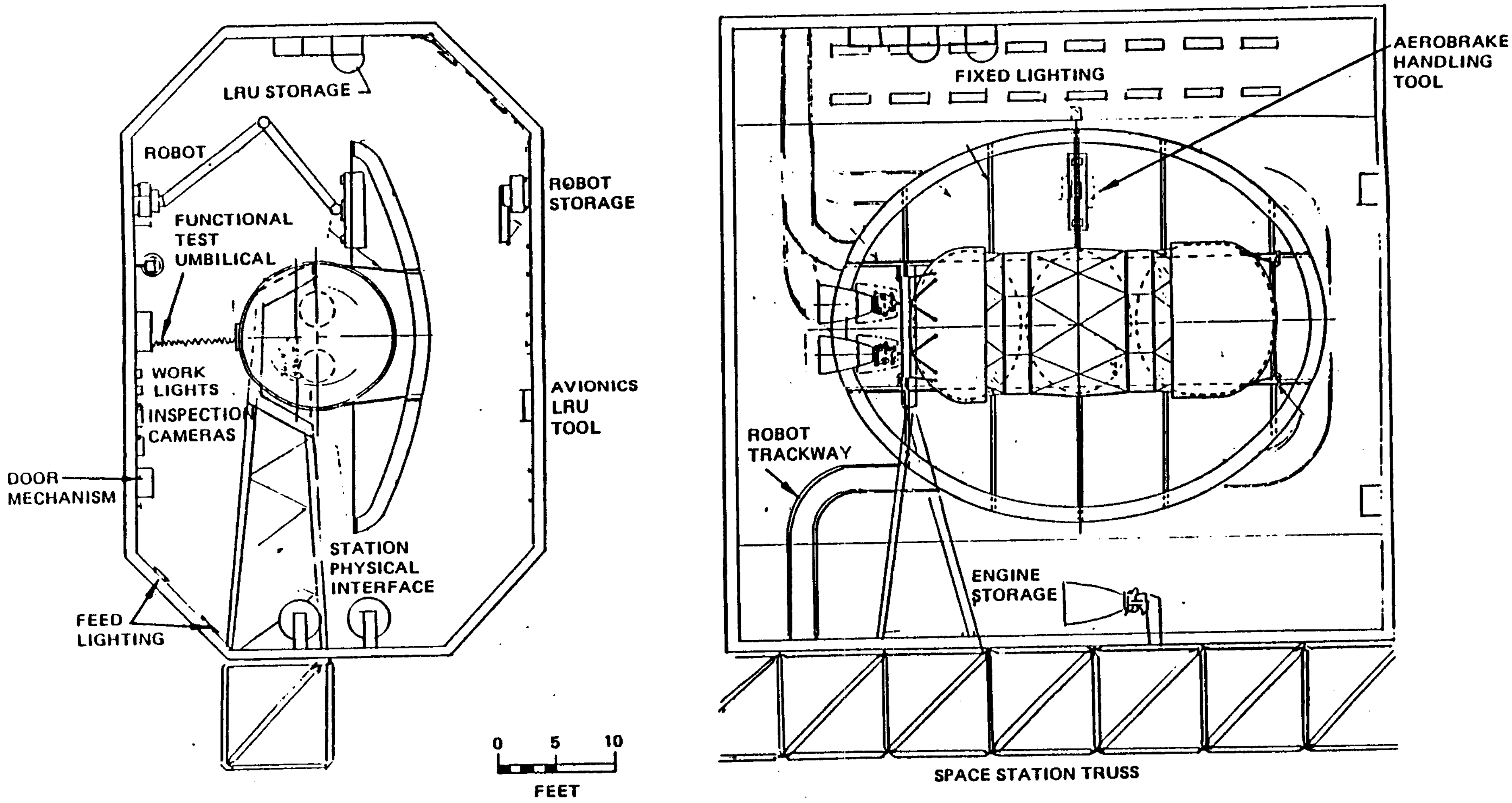


*Figure 3.1-9 Interior Arrangement — Shaped Brake OTV Hangar*

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### 3.1.4 Hangar Comparison

The overall physical characteristics of the hangars associated with each OTV concept are presented in figure 3.1-10. All but the hangar for the GBOTV auxiliary propellant tank have been sized for performing servicing within the hangar. No on-orbit servicing is necessary on the auxiliary propellant tank.

The dimensions, surface area and drag area are based on the size of the OTV's and the required clearances. Weights are based on table presented in section 3.1.3. The number of sections relate to how many parts must be delivered to orbit. Because of its size, the ballute OTV has the least demanding requirements in terms of hangar.

## 3.2 PROPELLANT STORAGE AND TRANSFER SYSTEM

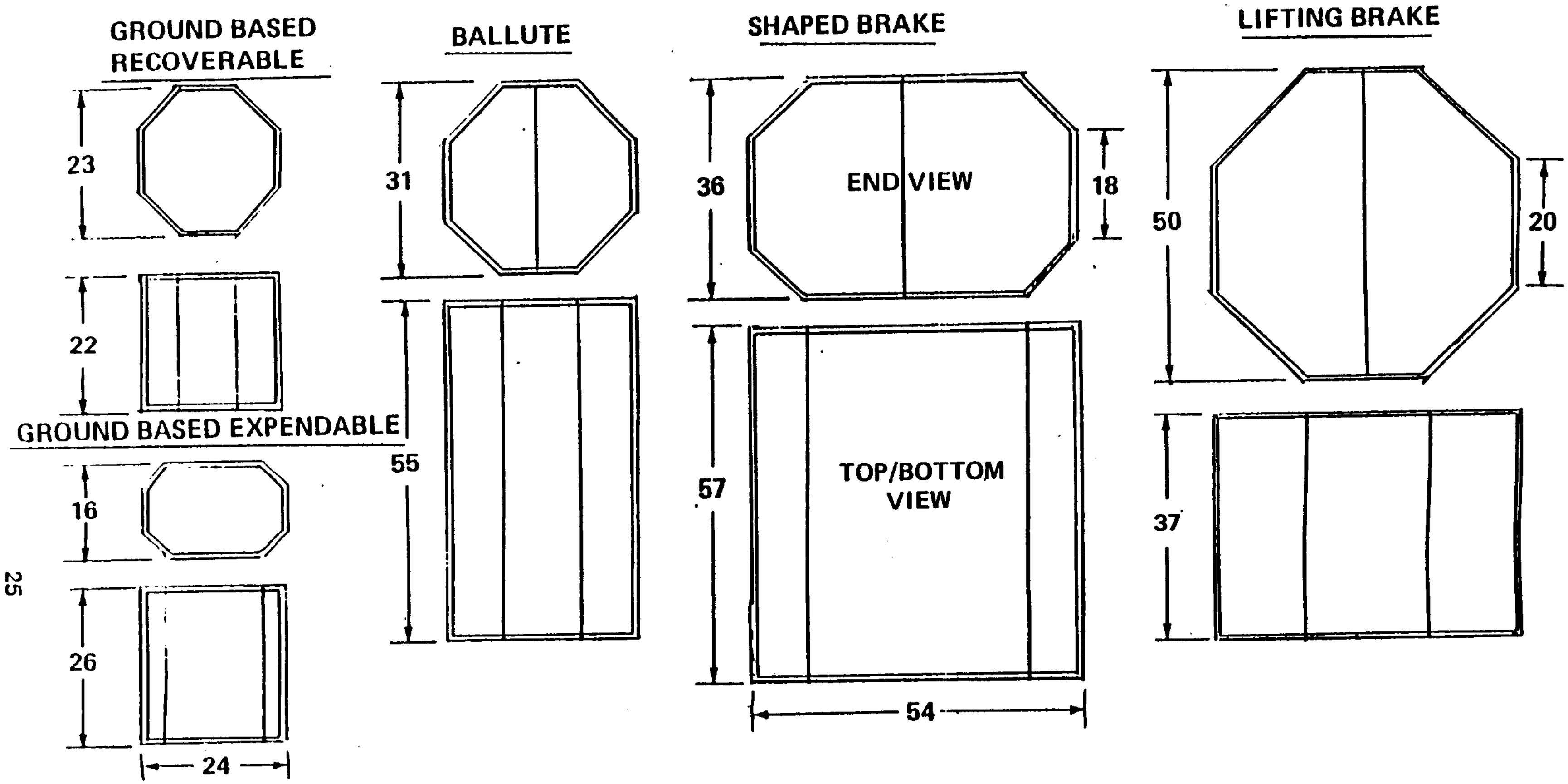
This section provides a summary of the propellant storage and transfer system located at the station. Additional information concerning all aspects of propellant logistics can be found in volume II, Book 4, Section 3.0.

### 3.2.1 Requirements And Assumptions

Liquid oxygen and hydrogen propellant for OTV will be delivered to the station using a combination of dedicated tankers and scavenging. Based on the low mission model, the on-orbit storage requirement is 185,000 lbm maximum for the case of performing a manned GEO sortie and a rescue mission in addition to receiving propellant from two scavenging flights but without any delivery from a dedicated tanker. A typical annual (year 2001) propellant handling schedule consists of 9 OTV loadings (average 53K lbm), 7 tanker deliveries (60 Klbm), and 13 deliveries of scavenged propellant (avg. 14K-lbm ea.). The significant requirement imposed by the Space Station program is that no propellant or gases will be vented. See Volume II, Book 4, Sections 3.4 and 3.5 for additional discussion of venting and non-venting implications.

### 3.2.2 Trades

The majority of the trades associated with propellant logistics have been described in Volume II Book 4. One trade not reported in that document is that of where the propellant should be located. Based on the reference Space Station program, propellant would be located at the station and acquired through use of surface tension screens within the tanks. Concerns regarding the efficiency of the surface tension screens, impact of the no vent rule, and slosh and cg impact on materials processing resulted in a cursory examination of several other concepts. All three options are shown in figure 3.2-1.




| | GROUND BASED | BALLUTE | SHAPED BRAKE | LIFTING BRAKE |
|---|---|---|---|---|
| WEIGHT | 2111 & 2175 | 5239 | 8979 | 7224 |
| AREA ($FT^2$) | 2446 & 2540 | 7080 | 12620 | 10020 |
| DRAG SECTION ($FT^2$) | 506 & 416 | 1705 | 1944 | 1850 |
| SECTIONS | 16 & 20 | 42 | 72 | 60 |

*Figure 3.1-10 Hangar Comparisons*

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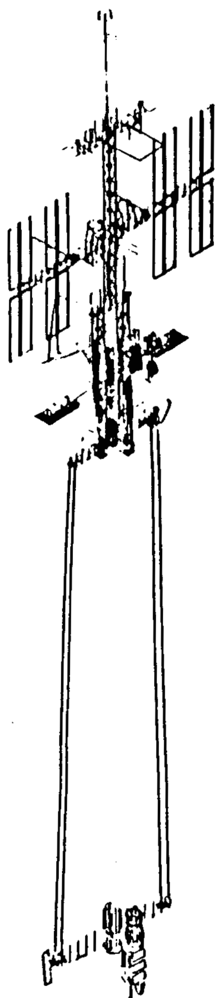

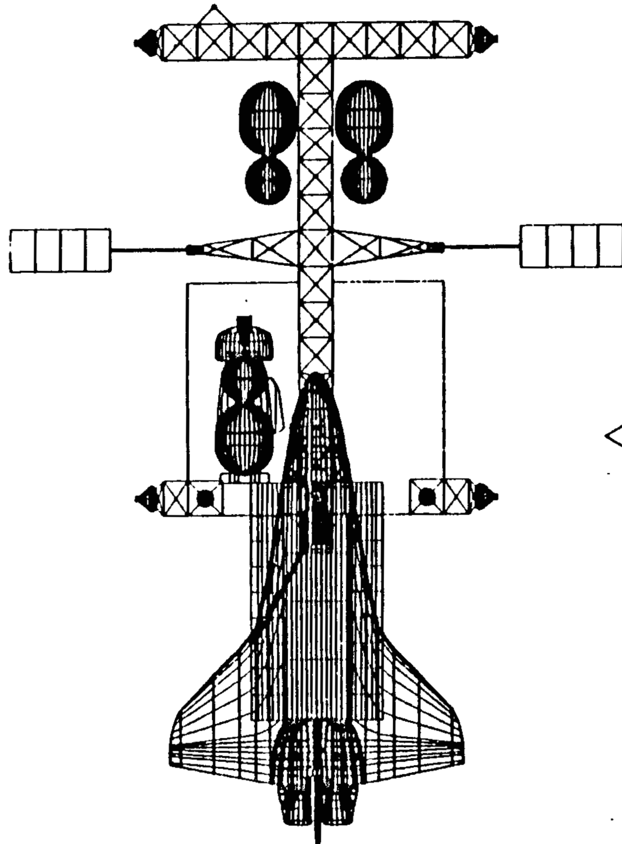

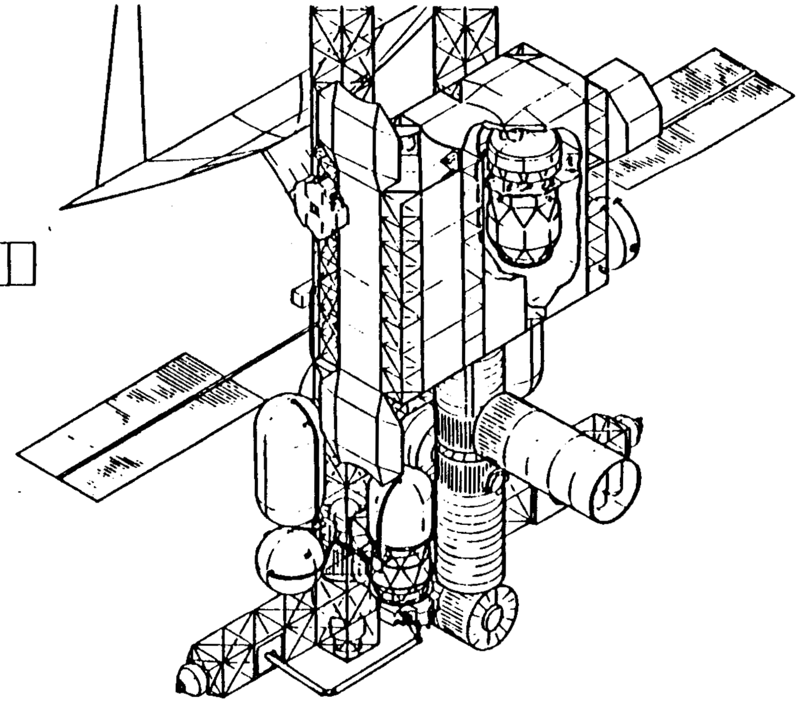

| | | | |
|---|---|---|---|
| CONCEPT ➡ | • AT STATION WITH TETHERED GRAVITY GRADIENT LIQUID SETTLING | • FREE FLYER WITH CENTRIFUGAL LIQUID SETTLING | • AT SPACE STATION WITH SURFACE TENSION LIQUID ACQUISITION |
| ASSESSMENT ➡ | • OPERATIONAL ISSUES | • DELTA + $250M | • SELECTED BASELINE |

*Figure 3.2-1 Propellant Storage Location Trades*

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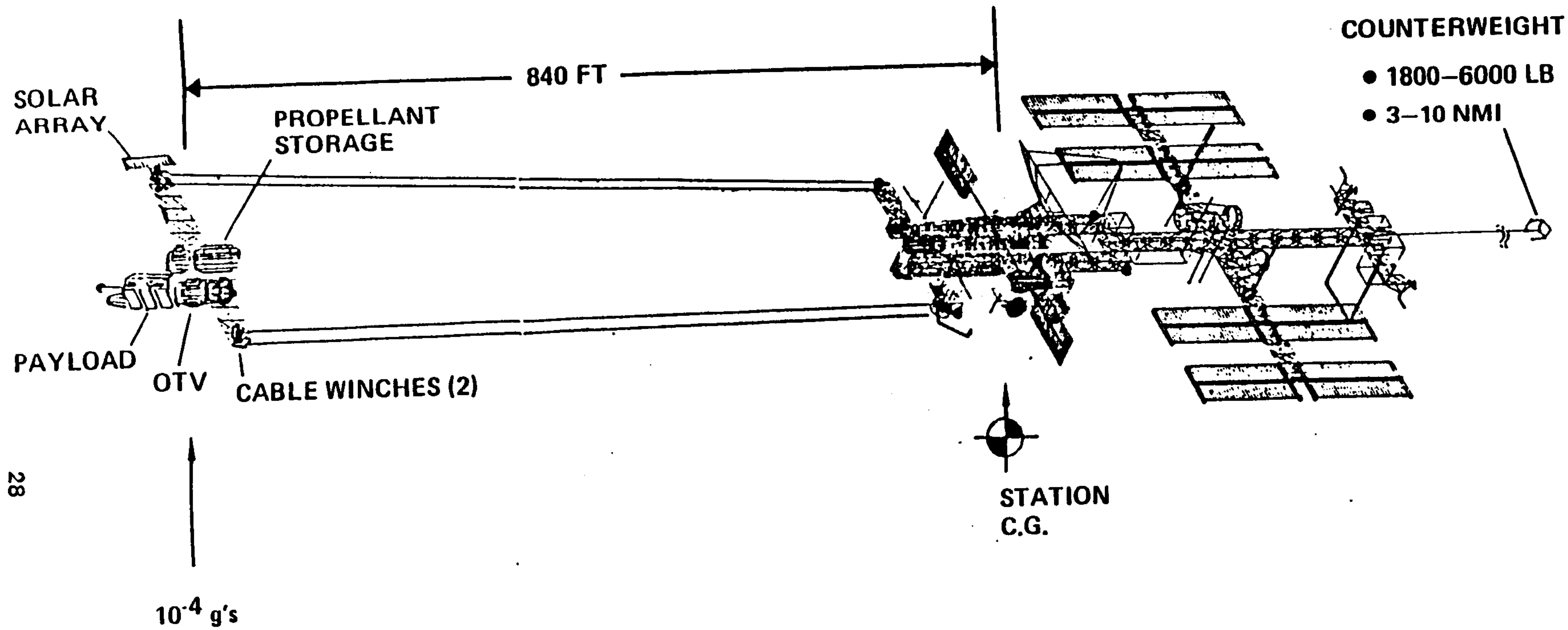
Option 1 had the propellant located at the station but had the tankage attached to a platform that could be deployed 840 ft. via a tether in a nadir direction and thus provide a gravity gradient up to $10^{-4}$ g's for transferring the propellant. Additional detail on this concept is shown in figure 3.2-2. Because the propellant storage system is a significant fraction of the total Space Station mass, moving it 840 feet would move the Station center of gravity enough to upset microgravity experiments. To solve this problem, a counterweight can be extended in the opposite direction. Since the mass x distance product determines the center of gravity shift, a smaller mass could be extended a distance of a few miles. The primary disadvantage of this concept is the operational issues associated with deploying and stowing of the tether propellant platform and counter balance.

A second option considered had the propellant located on a separate free flying platform. Further configuration data on this concept is presented in figure 3.2-3. Because a free-flying platform has a much smaller moment of inertia than the Space Station, a 0.2 rpm rotation rate induced by thrusters was found to be an efficient way to generate enough gravity to positively settle the propellant tanks. The thrusters were found to have less life-cycle mass required than a flywheel system. The free flying platform, however, must provide its own subsystems resulting in a cost penalty of approximately $250 million. An additional benefit of this concept however is that it could be used by DOD for integration of their payloads with the OTV.

Although there are concerns and benefits associated with each of the investigated concepts at this point we have selected storage at the station with screen acquisition as the baseline. We believe the operational problems (time line, g level impact and mechanism reliability) make the tether approach unacceptable until a more in depth analyses is performed including an assessment by the Space Station program. Although the separate free flying platform eliminates all of the concerns of the reference approach the additional cost is its principal disadvantage. A final thought regarding the selected approach is that it should force a more in depth analysis to be performed to determine if the concept really is viable at the space station within the imposed constraints.

### 3.2.3 Selected System

The propellant transfer system schematic shown by figure 3.2-4 is the configuration selected for propellant transfers to be accomplished at the Space Station. The system is arranged so that the tanker and OTV use a common docking port and the same interfaces for the required fluid transfers. Gases vented from the tanks due to boiloff and during fluid transfer operations are captured, compressed and stored at approximately 2000




- ON STATION IS BASELINE, BUT
- CRYOGENIC FLUID TRANSFER HAS NOT BEEN DEMONSTRATED
- TETHER IS A BACKUP THAT WILL WORK IF PROBLEMS WITH ZERO GEE TRANSFER OCCUR

*Figure 3.2-2 Center Balanced Tethered Propellant Platform*

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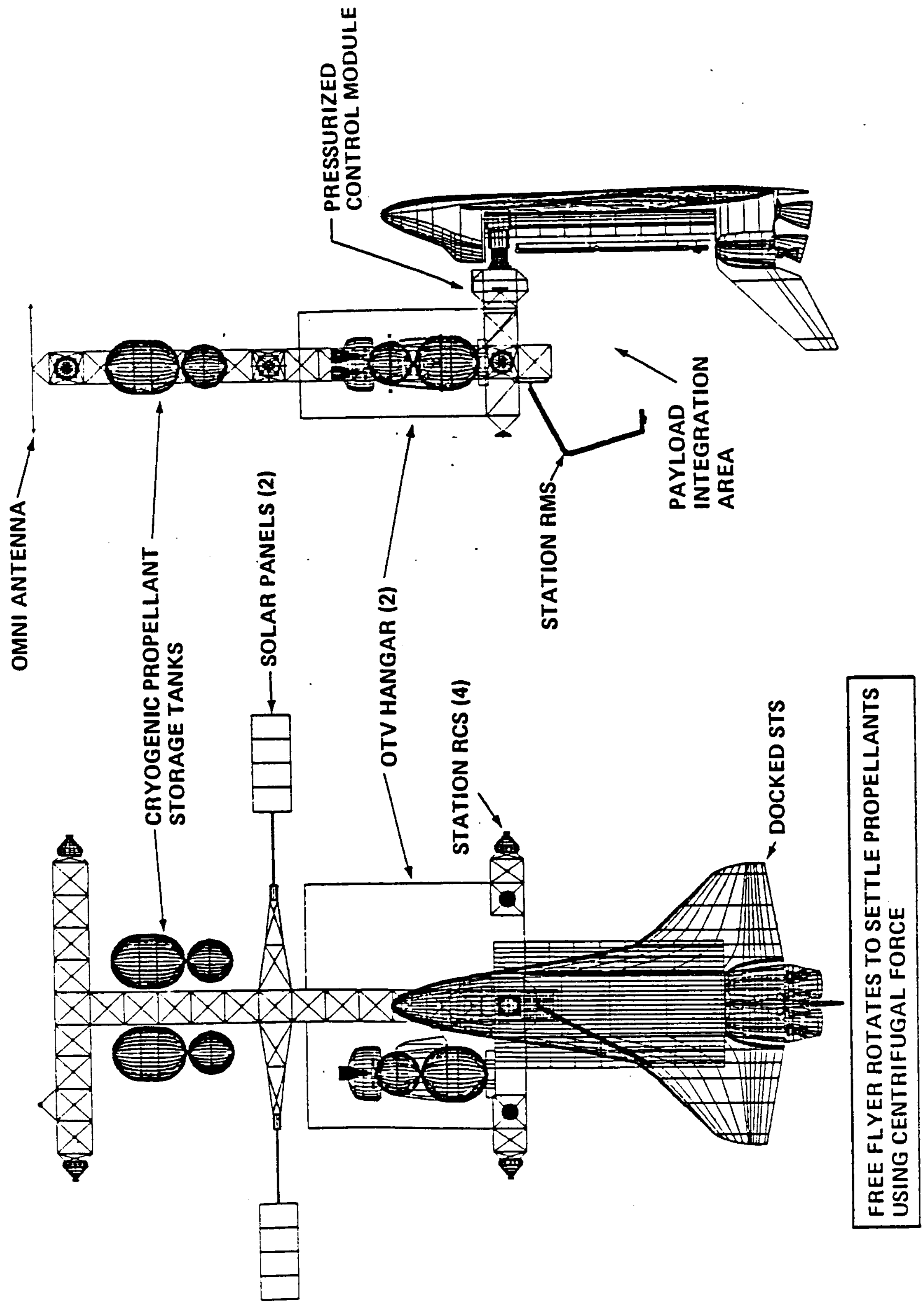


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*Figure 3.2-3 Free Flying Propellant Platform*

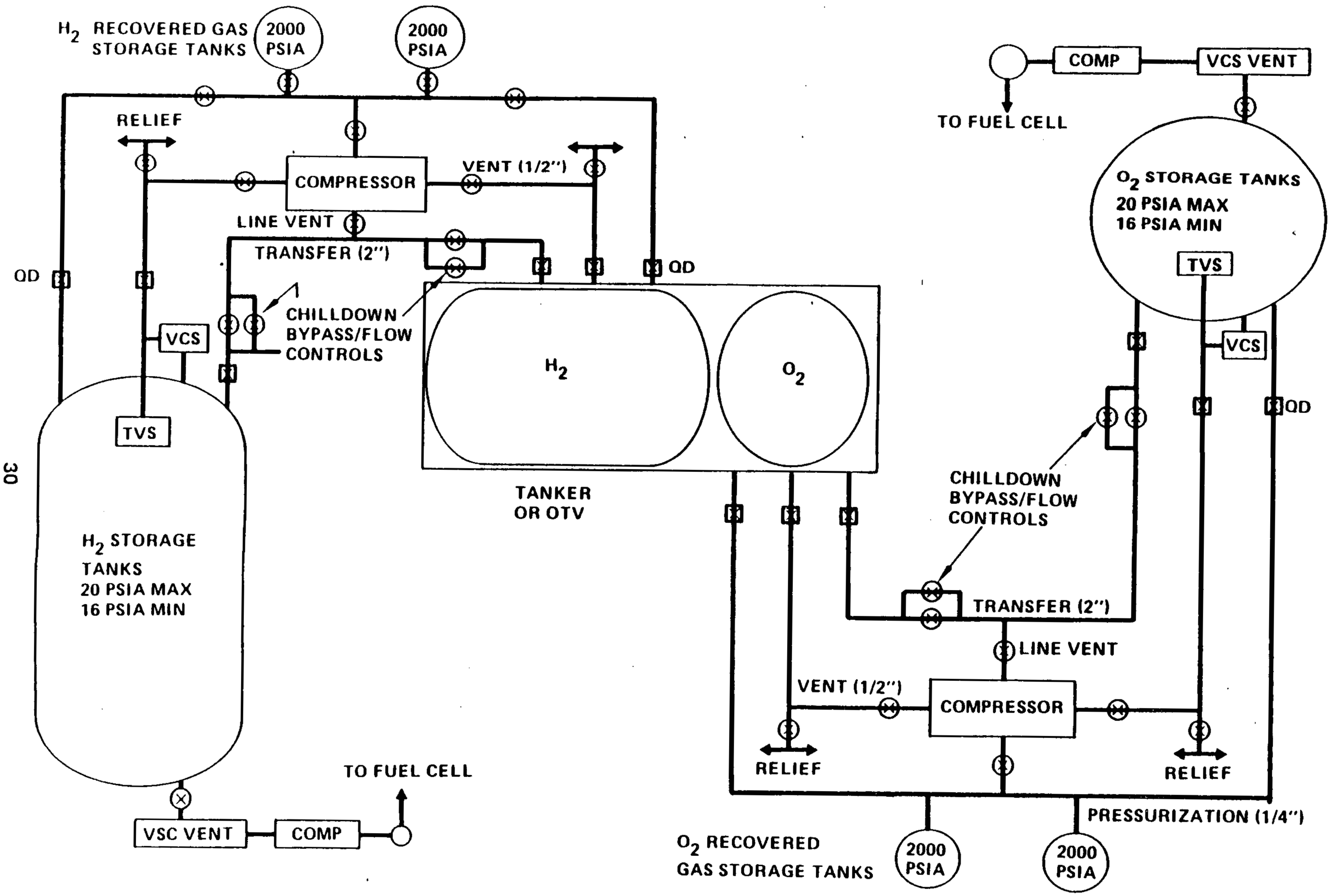


*Figure 3.2-4. Space Station Propellant Transfer System Schematic*

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psia. The compressed gases are used to effect pressurized fluid transfer from the tanker to the storage tanks or from the storage tanks to the OTV by selectively opening and closing appropriate valves. The system is intended to capture all gases vented from the tanks and therefore will not violate the Space Station no vent requirement.

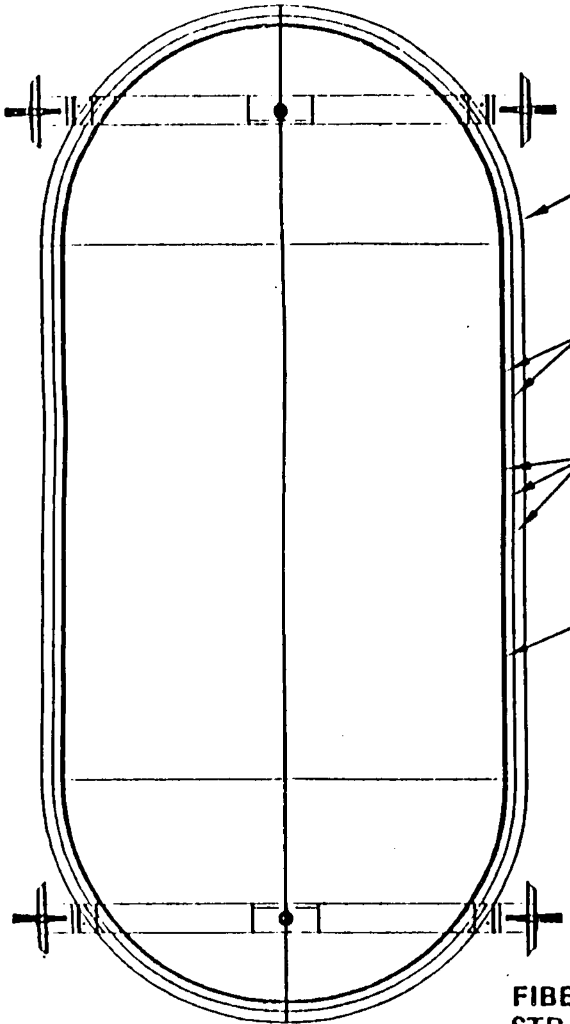
The configurations of the Space Station hydrogen and oxygen storage tanks are shown by figures 3.2-5 and 3.2-6. Two tank sets will be permanently attached to the Space Station. The tanks will be launched empty but pressurized with helium. Liquid acquisition devices consisting of eight screen channels are included in each tank to provide liquid at the outlets for fluid transfer in the low "g" Space Station environment. The dewar insulation annulus will be pressurized with helium during ground and launch operations to maintain insulation cleanliness and integrity. The insulation annulus will be vented to vacuum on orbit to obtain dewar conditions and thermal performance. Boiloff rates for these tanks were estimated based on operating vapor cooled shields. A hydrogen boiloff rate of 7 lbm per tank/day and an oxygen boiloff of 13 lbm per tank/day were estimated. Acceptance testing of the tanks thermal performance will be accomplished on the ground in a vacuum chamber with the insulation evacuated and re-pressurized after test completion.

The Space Station requirement of no fluid venting has a major impact on the storage and transfer of cryogenic fluids. The gases which must be captured and stored include boiloff and chill down losses and OTV reserves and residuals returned to the station. Approximately 6700 lbm of oxygen and 2520 lbm of hydrogen will accumulate in a 90 day period. Assuming the gasses are stored at 2000 psia and 500 degrees Rankine would require ten 9 ft diameter pressure vessels for hydrogen storage and two 8 ft diameter pressure vessels for oxygen storage as shown by figure 3.2-7 if none of the gases are used for a 90 day period.

The storage requirements for the surplus gases could be reduced by using fuel cells to convert a fraction of the gases to 84 lbm of water per day and produce net power of approximately 3.9 kw as shown in figure 3.2-8. The excess of hydrogen available above the fuel cells stoichiometric ratio would still require six 9 ft diameter pressure vessels if none were used in the 90 day period.

### 3.3 SUPPORT EQUIPMENT

Support equipment is defined as that which is necessary to service, maintain, and move the OTV while within the hangar. An indication of the specific items required and their quantities to support each OTV concept are shown in table 3.3-1. Except for the aerobrake handling tool and size of mobile robots all of the space based OTV concepts use essentially the same equipment. Since all ground based OTV servicing is done on the




## DESIGN PARAMETERS

- PRESSURE VESSEL
  - DIAMETER, 13 FT
  - LENGTH, 28.93 FT
  - WE GHT, 1397 LBM
- DEBRIS/METEOROID SHELL
  - DIAMETER 14.33 FT
  - LENGTH 30.26 FT
  - WEIGHT, 1652 LBM
- CAPACITY AT 17.5 PSIA
  - 13286 LBM WITH 7% ULLAGE
- INSULATION SYSTEM
  - 120 LAYERS MLI
  - 2 VAPOR COOLED SHIELDS WITHIN MLI
  - BOILOFF ~ 7 LBM/DAY
  - WEIGHT, 1114 LBM
- LIQUID ACQUISITION SYSTEM
  - 8 CHANNELS ON MERIDIANS
  - CHANNELS 8 IN. BY 2 IN.
  - 2 SCREENS 325 x 2300 ONE SIDE OF CHANNEL
  - WEIGHT, 781 LBM
- TOTAL TANK WEIGHT, 5686
- ASE WEIGHT 598 LBM
- DEVELOPMENT COST, $\$106.3 \times 10^6$
- PRODUCTION COST, $\$9.9 \times 10^6$ FIRST UNIT

*Figure 3.2-5 Space Station Hydrogen Storage Tank Baseline Concept*

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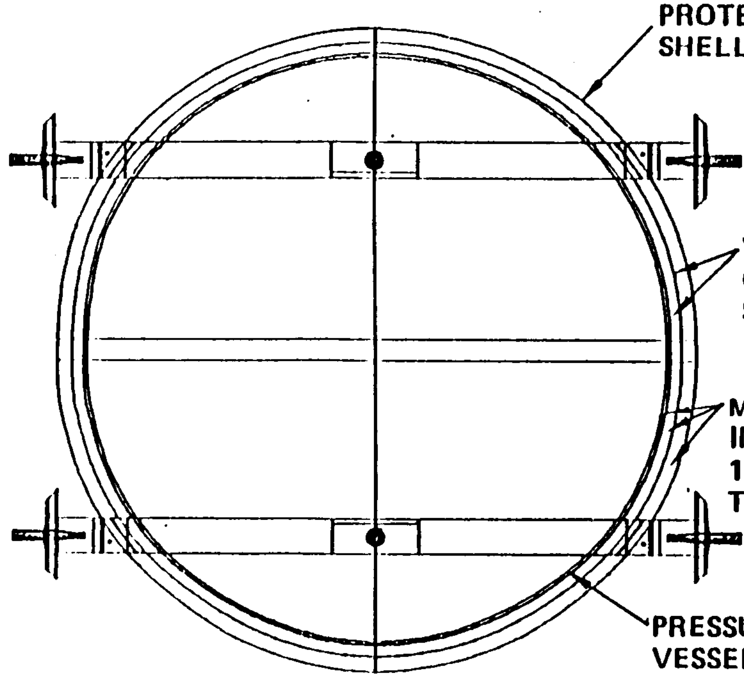


DESIGN PARAMETERS

- PRESSURE VESSEL
  - DIAMETER, 13 FT
  - LENGTH, 13.47 FT
  - WEIGHT, 438 LBM
- DEBRIS/METEOROID SHELL
  - DIAMETER, 14.33 FT
  - LENGTH, 14.8 FT
  - WEIGHT, 829
- CAPACITY AT 17.5 PSIA
  - 79714 LBM WITH 7% ULAGE
- INSULATION SYSTEM
  - 120 LAYERS MLI
  - 2 VAPOR COOLED SHIELDS WITHIN MLI
  - BOILOFF, 13 LBM/DAY
- LIQUID ACQUISITION SYSTEM
  - 8 CHANNELS ON MERIDIANS
  - CHANNELS 4 IN. BY 1 IN.
  - 2 SCREENS 325 x 2300 ON ONE SIDE OF CHANNEL
  - WEIGHT, 260 LBM
- TOTAL TANK WEIGHT, 2063 LB
- ASE WEIGHT, 598 LBM
- DEVELOPMENT COSTS, $\$48.8 \times 10^6$
- PRODUCTION COST, $\$4.7 \times 10^6$

*Figure 3.2-6 Space Station Oxygen Storage Tank Baseline Concept*

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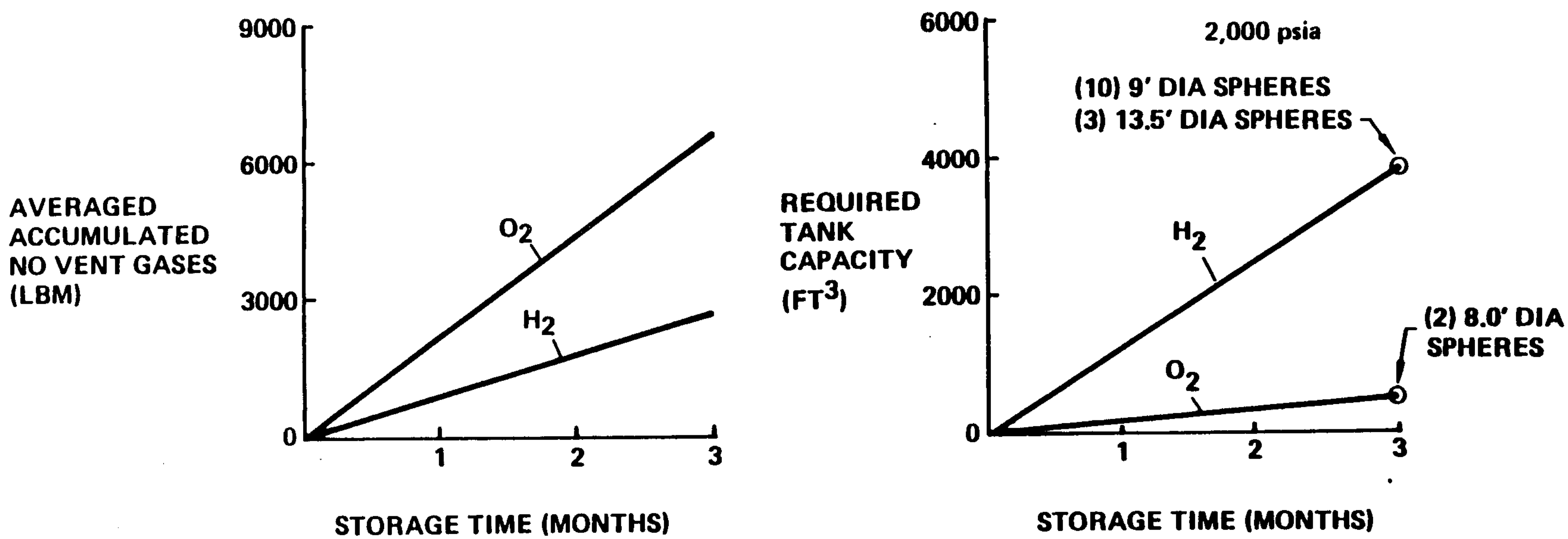


*Figure 3.2-7. Gas Storage Tank Sizing for "No Vent" Requirement*

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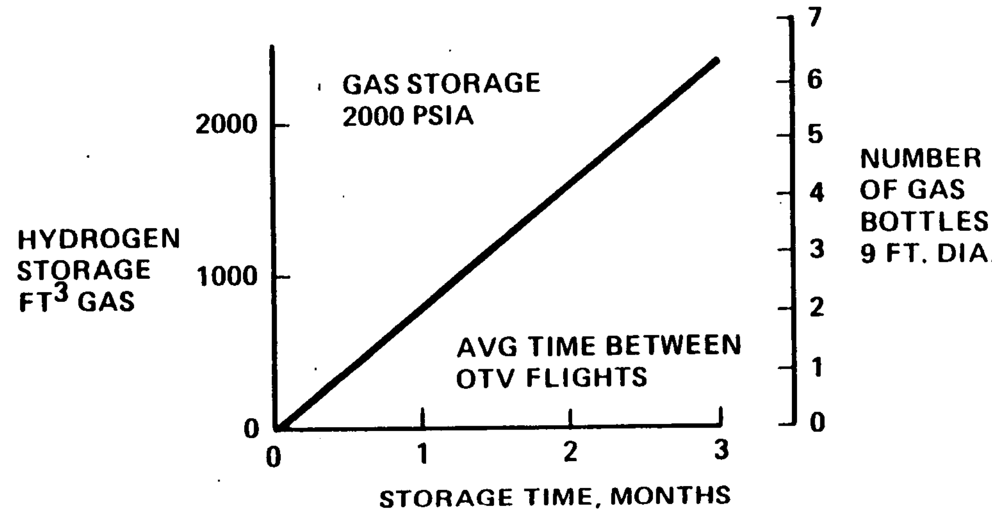
| ELECTRICITY | DAILY SUPPLY, LBM | |
|---|---|---|
| | $H_2$ | $O_2$ |
| BOILOFF (2 TANK SETS) | 14.1 | 25.5 |
| FLIGHT LOSSES AT 8 FLIGHTS/YEAR | | |
| CHILLDOWN | 7.8 | 12.3 |
| RESERVES | 4.1 | 24.0 |
| RESIDUALS | 2.0 | 12.5 |
| TOTAL | 28.0 | 74.3 |
| NET AT STOICHIOMETRIC | 9.36 | 74.3 |
| POWER AVAILABLE AT 0.9 LB/KWH | 3.9 KW | |
| NET WATER | 83.7 LBM/DAY | |
| RESIDUAL $H_2$ | 18.6 LBM/DAY | |
| AVG. POWER FOR COMPRESSION | 0.4 KW | |
| NET POWER AVAILABLE | 3.5 KW | |



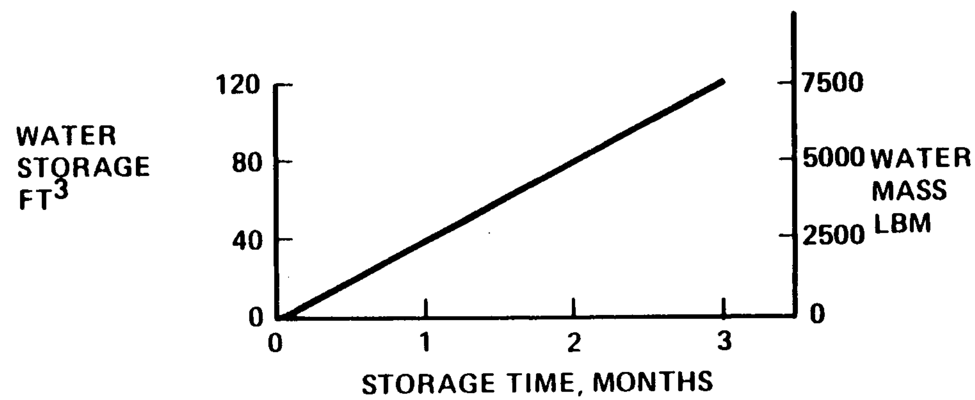




Figure 3.2-8. OTV Surplus Gas Use by Space Station

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*Table 3.3-1 Hangar Support Equipment Requirements*

| ITEMS NEEDED | SPACE-BASED | | | GROUND-BASED |
|---|---|---|---|---|
| | BALLUTE | SHAPED BRAKE | LIFTING BRAKE | |
| AEROBRAKING HANDLING TOOL | 1 | 1 | 1 | |
| BALLUTE HANDLING TOOL | 1 | - | - | - |
| ENGINE HANDLING TOOL | 1 | 1 | 1 | - |
| INSPECTION CAMERA | 4 | 4 | 4 | - |
| FUNCTIONAL TEST UMBILICAL | 1 | 1 | 1 | 1 |
| AUXILIARY TANK STORAGE | - | - | - | 1 |
| WORK LIGHTS | 2 | 2 | 2 | 6 |
| FIXED LIGHTS | 1 | 1 | 1 | - |
| AVIONICS LRU TOOL | 1 | 1 | 1 | - |
| ENGINE STORAGE FIXTURE | 2 | 2 | 2 | - |
| LRU STORAGE FIXTURE | 15 | 15 | 15 | |
| BALLUTE STORAGE FIXTURE | 2 | - | - | - |
| TPS STORAGE | - | - | 1 | - |
| MOBILE ROBOT (aka Small RMS) | 4 | 4 | 4 | - |
| STANDARD END EFFECTOR | 1 | 1 | 1 | - |
| ASTRONAUT FOOT RESTRAINT/CONTROL PANEL | 2 | 2 | 2 | - |
| ROBOT TRACKWAY | 1 | 1 | 1 | - |
| ELEMENT INTEGRATION SUPPORT STAND | 1 | 1 | 1 | 1 |



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ground, there is almost no support equipment on the Station. Concepts of tools associated with the rigid TPS aeroshell removal for the ballute and lifting brake, engine removal and mobile robot are shown in figure 3.3-1. The mass and size for most of the support equipment is presented in section 5.0.

### 3.4 Pressurized Module

Use of a Space Station pressurized module is desirable to support OTV checkout, software loading, propellant transfer, and servicing, both remote and EVA. The Orbital Maneuvering Vehicle (OMV) will precede the OTV on the Space Station. Aside from additional software requirements, the OMV control system on the Space Station appears adequate to support the OTV as well. It will be necessary to shift control of one of the vehicles to another console aboard the Space Station when both vehicles are operating at the same time.

Our concept for use of a pressurized module is shown in figure 3.4.-1. The concept assumes that at the time the OTV is operating from the Space Station, there will be a third Habitation Module installed on the Space Station. Our configuration for the module is a rearrangement of Habitation Module #2. It places the operations center and maintenance/repair station near the external airlock which leads to the OTV hangar interior. We suggest, if possible, placing windows in the module which allow direct observation of the hangar interior, similar to the aft flight deck of the Space Shuttle.

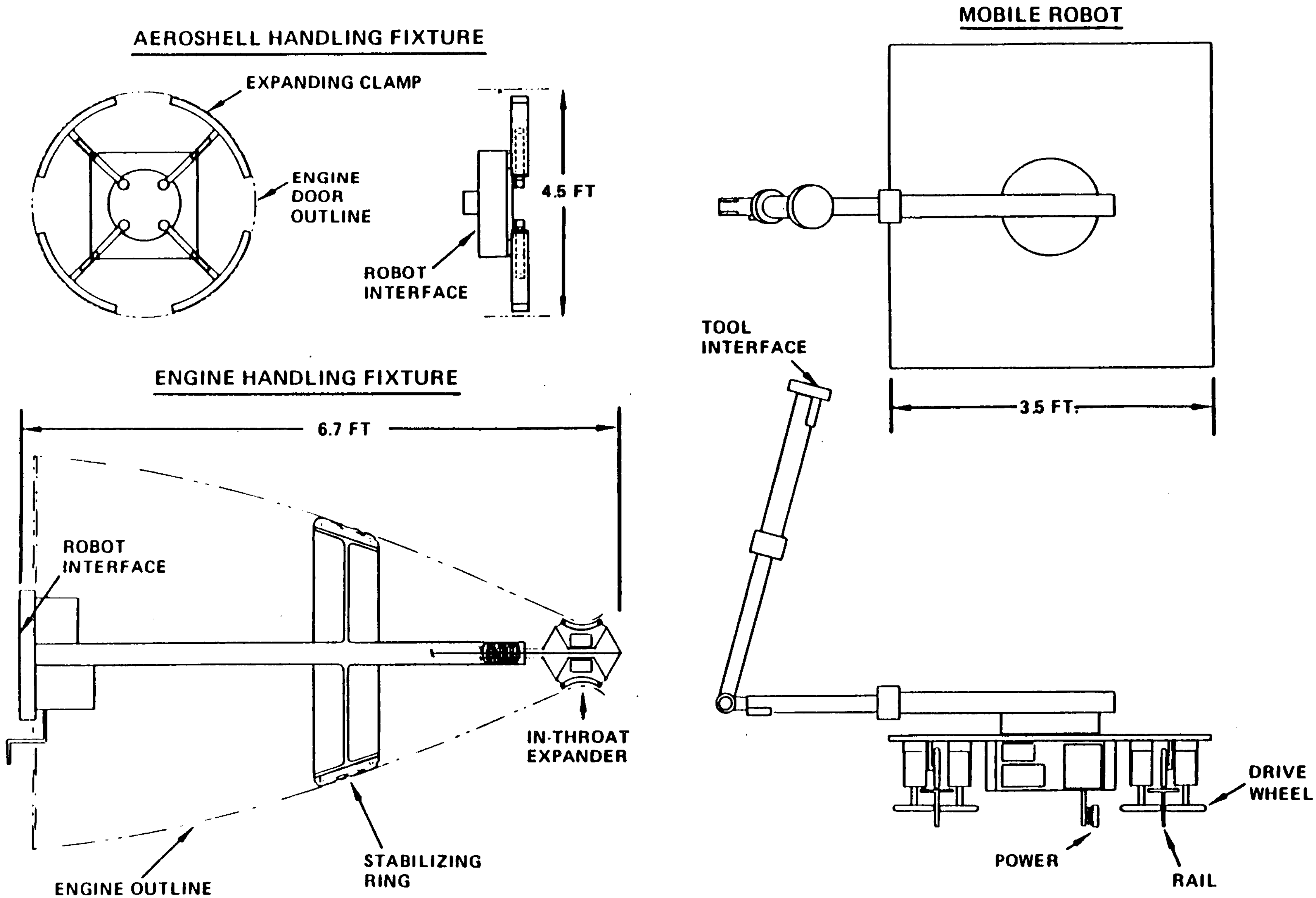


*Figure 3.3-1. Support Equipment - Fixtures*

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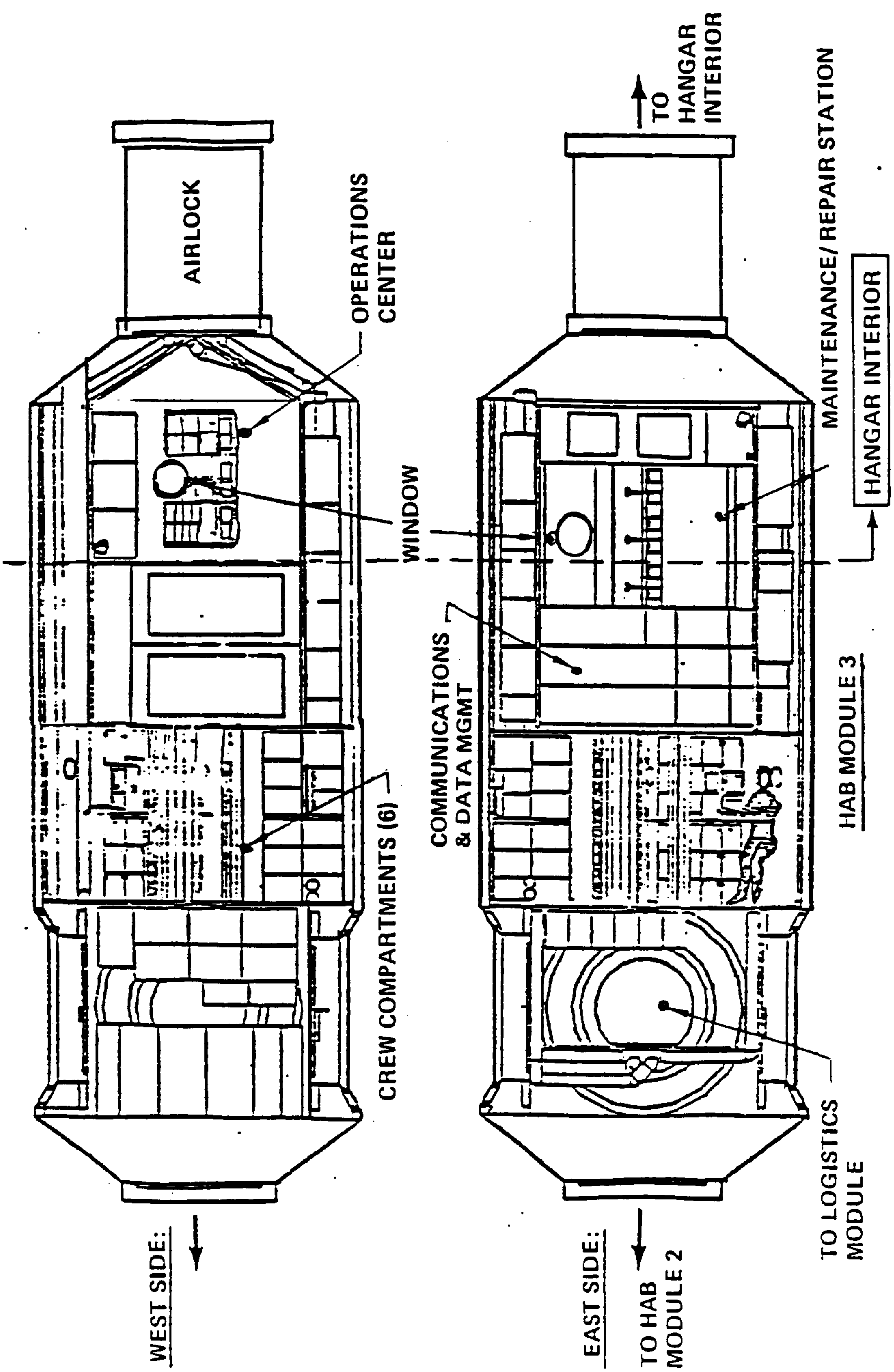


*Figure 3.4-1 Pressurized Module for OTV Support*

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# 4.0 STATION INTEGRATION

This section discusses the considerations in locating the OTV accommodations at the station, the selected arrangement, and the major handling operations involving the OTV, accommodations and station.

## 4.1 Accommodations Installation

### 4.1.1 Considerations

Table 4.1-1 identifies a number of factors that should be taken into consideration in placing the OTV accommodations on the FOC Space Station sometimes referred to as growth station. The Station structural requirements would be simplified by placing the propellant storage tanks and common modules near each other since they comprise the majority of the station mass. The propellant storage tanks have a very large impact on Station center of gravity location, since their contents range from 11,000 to 180,000 lb. Therefore there is a desire to place them near the Station center of gravity. If possible, they should be in a location that provides shade from the Sun, in order to reduce boiloff losses. The tank sets should be close together to allow OTV filling from both sets for a given mission. Hangar placement should allow for addition of a second hangar, although the second hangar need not be a servicing hangar unless very high flight rates (more than 25 per year) are required. Direct access to the hangar from the pressurized modules minimizes EVA costs by reducing travel time to the work location.

The OTV-payload integration stand should be close to the payload storage and OTV storage (hangar) locations to minimize transfer operation times. For large payloads, such as a GEO platform which is unfolded before launch, sufficient clearance for all the payload appendages is required. By locating the stand adjacent to the propellant storage tanks, a physical transfer operation can be avoided.

Another major location consideration is the restrictions imposed by the station itself as indicated by figure 4.1-1. The electrical power system and space-viewing instruments eliminate use of the top end of the power-tower Station configuration. Several regions are eliminated because of reaction control system plume impingement. Main radiator motion sweeps out a volume around the Station, and pressurized module radiators require a view of space which precludes placing OTV elements adjacent to them. Also shown on this figure are the c.g.'s for the station with and without the orbiter. To minimize center-of-gravity shift on the station, the propellant storage tanks should be located near the CG.

*Table 4.1-1 OTV Accommodations Location Considerations*

- OVERALL STATION
  - PRESSURIZED MODULES, ORBITER, AND STORAGE TANKS COMPRISE 2/3 OF SPACE STATION MASS
  - MINIMIZE STRUCTURAL REQUIREMENTS BY KEEPING THESE ELEMENTS TOGETHER
- PROPELLANT TANKS
  - TANKS PREFER SHADED LOCATION TO MINIMIZE HEAT INPUT
  - FILL AND DRAIN EFFECTS MINIMIZED BY PLACING TANKS NEAR STATION C.G.
  - LOGISTICS IMPROVED BY BEING ABLE TO LOAD OTV FROM BOTH TANK SETS FOR A GIVEN MISSION
- HANGAR
  - ROOM FOR GROWTH TO TWO HANGARS
  - DIRECT EVA ACCESS—MINIMIZES EVA COSTS
- PAYLOAD INTEGRATION STAND
  - CLOSE TO PAYLOAD STORAGE AND OTV HANGAR—MINIMIZES TRANSFER OPERATIONS
  - LARGE CLEAR AREA FOR LARGE PAYLOADS
  - CO-LOCATE WITH PROPELLANT STORAGE TANKS—ELIMINATE TRANSFER OPERATION

OTV-548

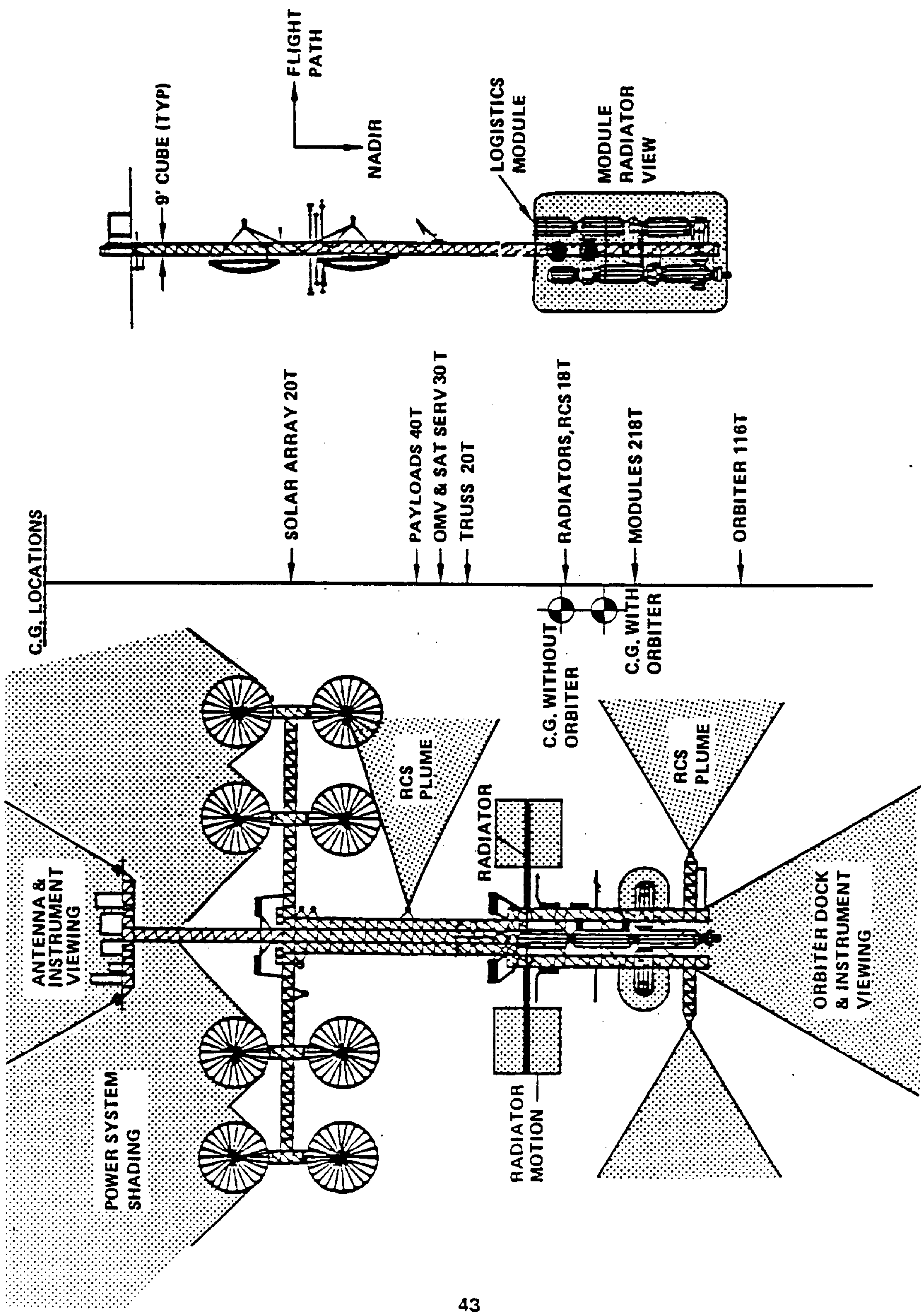



*Figure 4.1-1 Location Restrictions*

OTV-603

### 4.1.2 Selected Arrangement for SBOTV

The various restrictions and considerations on locating OTV accommodations elements dramatically reduced the number of viable arrangement candidates. Although several arrangements were investigated including placement of the hangar and propellant storage tanks at the base of the station each resulted in either more modifications to the basic station or had a greater impact on the c.g. than the selected arrangement.

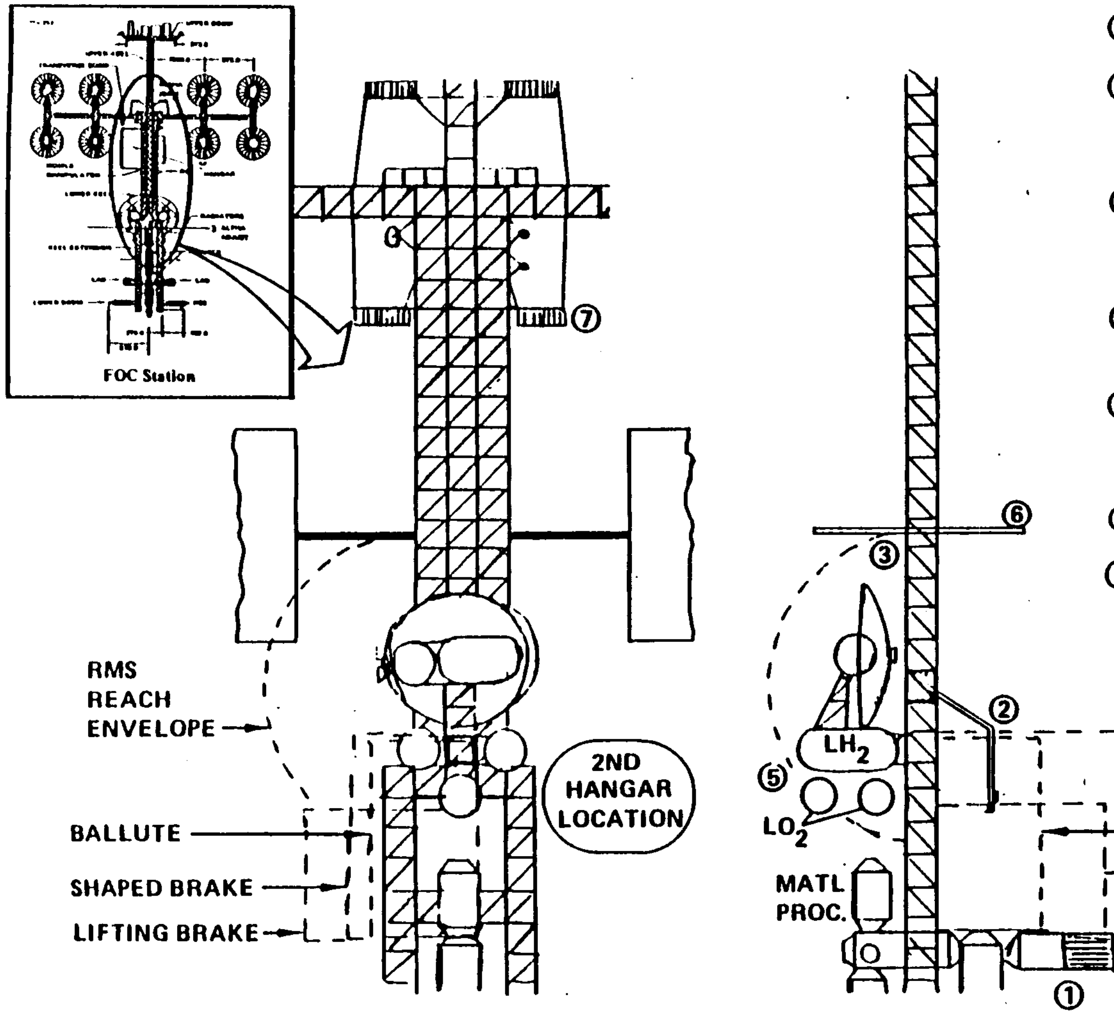
The selected arrangement and its rationale are presented in figure 4.1-2. The desire for direct EVA access between the habitat and hangar necessitated moving the Logistics Module from the end to the side docking port of the uppermost habitation module. To enable the MRMS to reach the OTV inside the hangar, the hangar must be oriented door upwards. The door cannot be downward due to interference with the pressurized modules. If it is oriented sideways, the MRMS reach will be insufficient. To minimize MRMS motion and because of the other location restrictions the OTV integration stand is located on the truss opposite the hangar. To allow for large payloads, the OTV is mounted on the integration stand with the payload interface pointing away from the truss.

The propellant storage tanks are located near the integration stand to eliminate another physical transfer after payload integration. The tanks are arranged to have the shortest propellant transfer line lengths possible, since there are losses incurred in cooling those lines. To minimize Station center of gravity shift as propellants are added or removed, the tanks are located near the Station vertical center of gravity. In addition, the tanks are located so as to balance the mass of the logistics module on the far side. This will keep the transverse center of gravity centered on the truss and enable the station to fly a vertical attitude.

These location decisions necessitate moving the Station radiators higher on the truss. In addition, the two payload storage stands that were located where the OTV facilities have been placed are now relocated to the solar array crossbar, where the other two stands were already located.

The selected arrangement of the major accommodation elements are also shown in figure 4.1-3. This arrangement is viewed as a good compromise of factors important to the station and to efficient operation of a space based OTV. Modifications to the Reference FOC Space Station include relocating the Logistics Module to the side of the upper Habitation Module, moving the payload storage stands that were in the middle of the Station up to the power system cross-beam, and adding a stub truss section to support the propellant storage and transfer system.

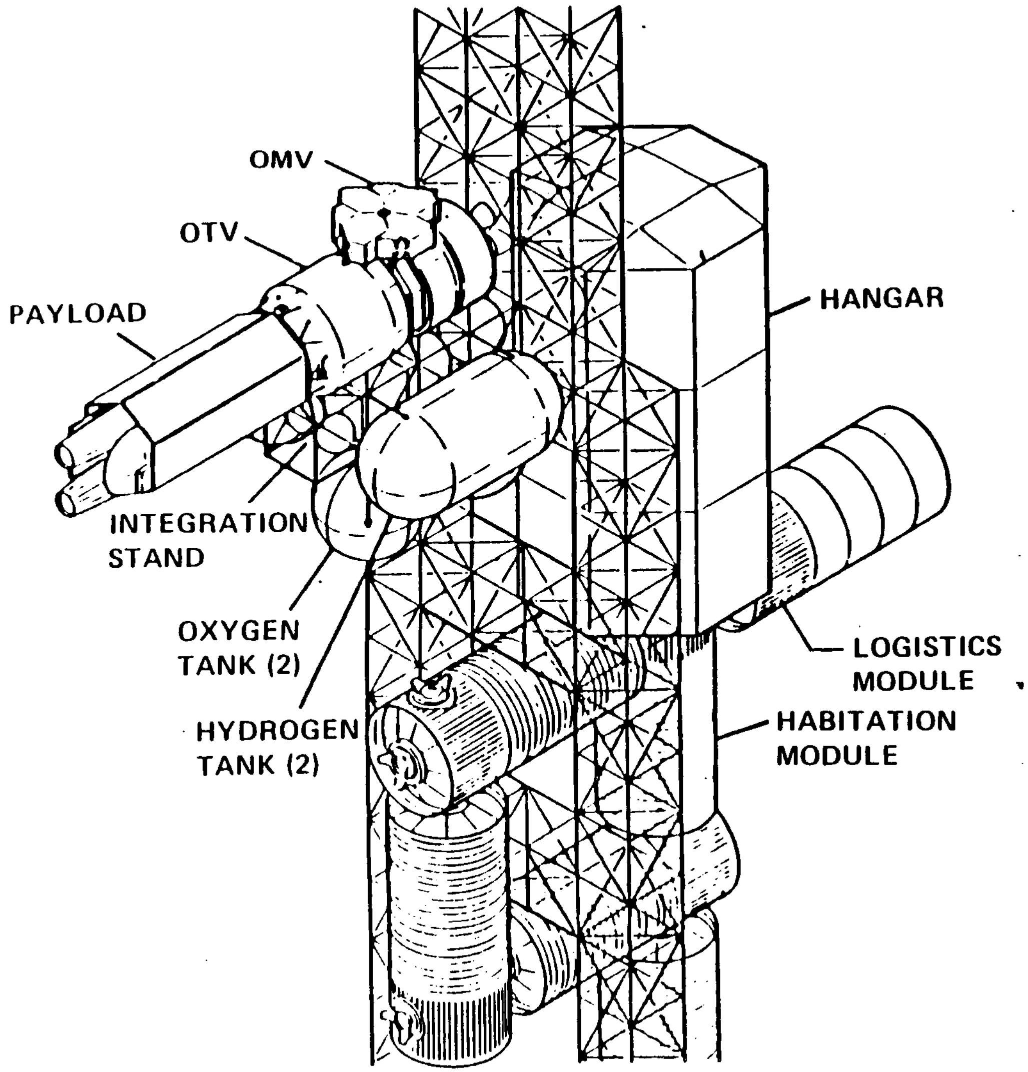
Hardware elements added to the Space Station to support OTV operations are the propellant storage tanks, the propellant transfer system, and the OTV servicing hangar.




1. EVA ACCESS REQUIRES RELOCATING LOGISTICS MODULE
2. HANGAR MUST BE ORIENTED DOOR UP TO ENABLE MRMS TO REACH OTV, AND SMALL SIDE TO TRUSS TO ALLOW FOR 2 HANGARS LATER
3. INTEGRATION STAND SHOULD BE WITHIN MRMS REACH WITHOUT TRANSLATION FROM HANGAR, OR TO DEPLOY POINT
4. VEHICLES ORIENTED PAYLOAD INTERFACE $-\vec{V}$, TO ALLOW FOR LARGE PAYLOADS
5. STORAGE TANKS LOCATED
   A) AT INTEGRATION STAND
   B) NEAR C.G.
   C) BALANCING LOGISTICS MODULE
6. RADIATORS RELOCATED HIGHER ON TRUSS
7. TWO PAYLOAD STORAGE STANDS RELOCATED ON TRUSS

*Figure 4.1-2 Accommodations Placement Rationale — Space Based OTV*

OTV-602




## FEATURES

1. GOOD COMPROMISE OF STATION C.G. CONSIDERATIONS, MOVEMENT AROUND STATION AND ACCESSIBILITY
2. HANGAR ADJACENT TO COMMON MODULE FOR DIRECT ACCESS
3. PROPELLANT STORAGE NEAR STATION VERTICAL C.G. AND BALANCES LOGISTICS MODULE OFFSET
4. INTEGRATION STAND NEAR C.G., PROPELLANT STORAGE AND HANGAR

*Figure 4.1-3. Selected Arrangement for SBOTV Accommodations*

OTV-829

### 4.1.3 Selected Arrangement For GBOTV

Accommodations for the GB OTV Concept only involve a small hangar for storage of an auxiliary propellant tank and an area to physically integrate the OTV, auxiliary tank, and payload. The arrangement of there elements is shown in figure 4.1-4. The operations indicated reflect use of either expendable auxiliary propellant tanks or reusable tanks. The preferred approach for the GB OTV is to use reusable tanks. The hangar in this application is used to provide thermal protection for the auxiliary tank to minimize boiloff while waiting to be integrated with the OTV. The integration area and payload storage area is adjacent to the hanger to minimize vehicle integration time and movement of the MRMS.

## 4.2 OPERATIONS

This section discusses several OTV operations that involve the OTV accommodations, and/or use of station provisions. Most notable of these include OTV/payload integration, launch and retrieval, and servicing via automation. Timeline and crew requirements are presented in Volume II Book 4.

### 4.2.1 OTV/Payload Integration

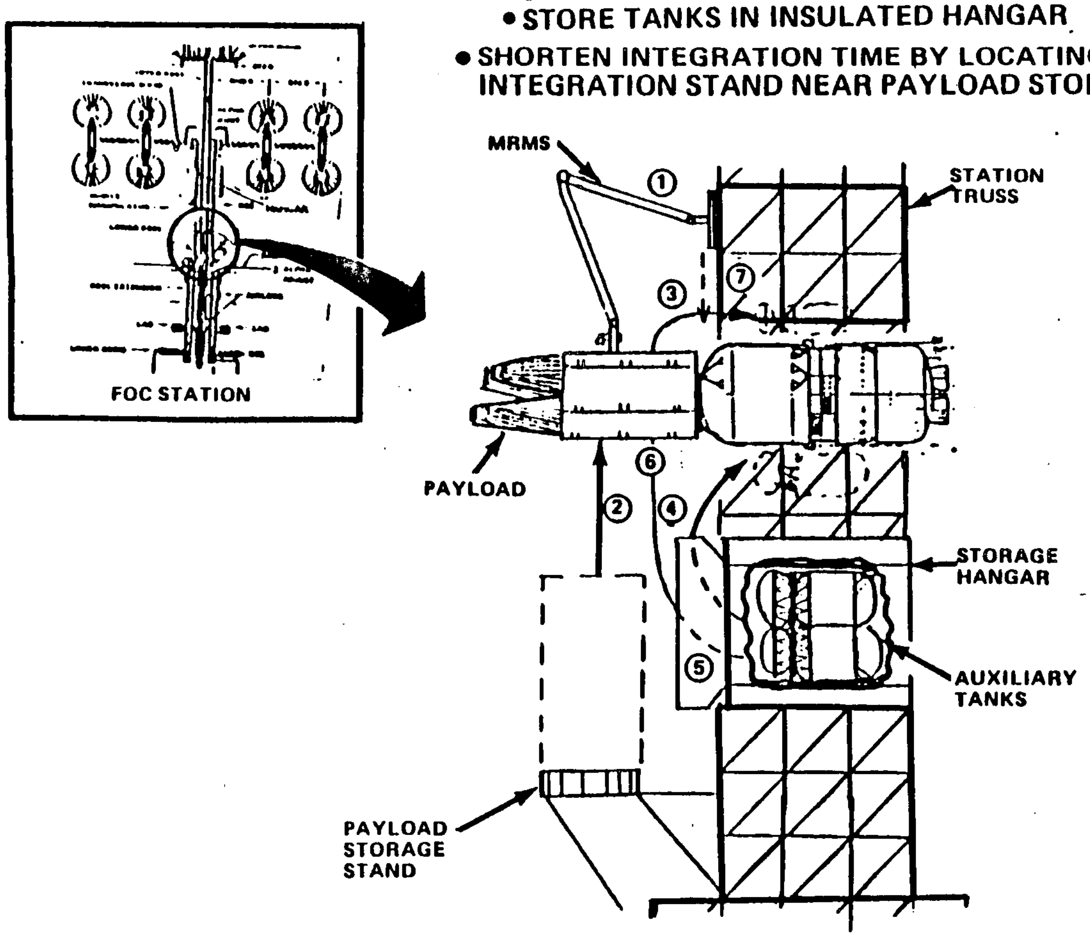
Movement of the OTV and payloads from their storage location to the integration area will be done through use of the MRMS. The operations associated with placement of the OTV on the integration stand are shown in figure 4.2-1. Once the hangar door is open the MRMS reaches into the hangar using the aeroshell handling fixture and pulls the OTV clear by translating up the Station truss. When the OTV is clear of the hangar, the MRMS swings the vehicle around the truss and orients it for placement on the integration stand. Finally the MRMS translates downward to place the OTV on the integration stand.

Payloads to be integrated with the OTV vary considerably in size and weight as indicated by Table 4.2-1.

Table 4.2.1 OTV Payload Characteristics

| PAYLOAD | SIZE | MASS(LB.) |
|---|---|---|
| Large Platform Deployed At Departure | 150x150x100 | 20,000 |
| Large Platform-Undeployed | 14x14x40 | 20,000' |
| Majority Of Payloads | 14x14x30 | 12,000 |

- STS TOO SMALL FOR 20K GEO DELIVERY—REQUIRES TWO LAUNCHES
- MINIMIZE BOILOFF LOSSES BY
  - LAUNCHING SMALLER AUXILIARY TANKS FIRST
  - STORE TANKS IN INSULATED HANGAR
- SHORTEN INTEGRATION TIME BY LOCATING STORAGE HANGAR AND INTEGRATION STAND NEAR PAYLOAD STORAGE




OPERATIONS – EXPENDABLE TANKS

1. PUT RMS IN POSITION
2. PUT PAYLOAD ON OTV
3. TRANSLATE RMS BASE
4. PUT FIRST AUXILIARY TANK ON
5. TAKE SECOND TANK OUT OF HANGAR
6. TRANSLATE RMS BASE
7. PUT SECOND TANK ON

OPERATIONS—REUSABLE TANKS

(NOT SHOWN)

1. PUT RMS IN POSITION
2. PUT AUXILIARY TANK ON OTV
3. PUT PAYLOAD ON OTV

*Figure 4.1-4 Selected Arrangement for GB OTV Accommodations*

OTV-668

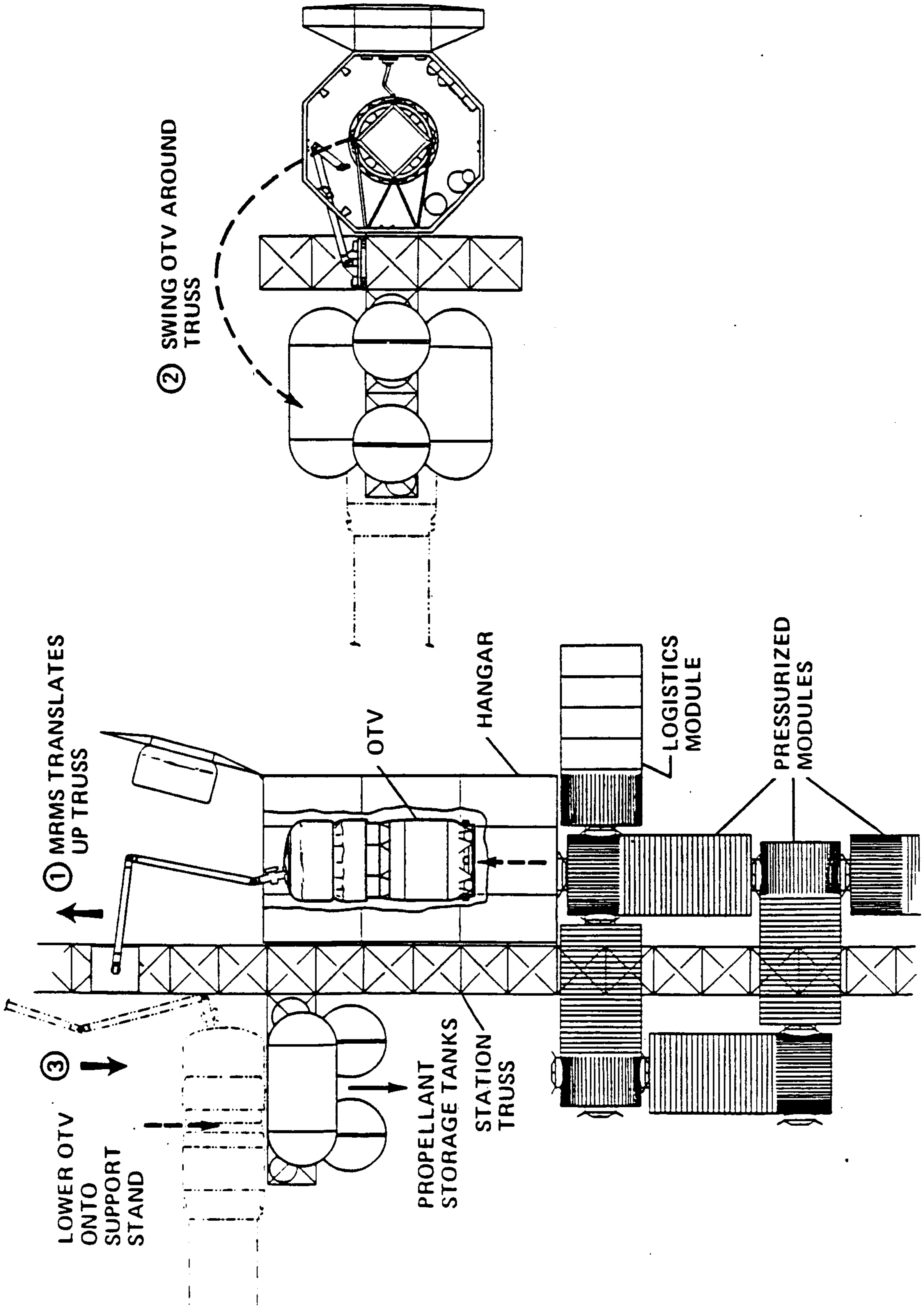



*Figure 4.2-1 OTV Movement with MRMS*

Comparison of payload integration operations for the ballute OTV and lifting or shaped brake OTV is presented in figure 4.2-2. The principal difference between the concepts is that the shaped or lifting brake OTV's require additional truss structure to enable attachment to the station and a longer MRMS to place the OMV which is used for launching.

The most demanding OTV/payload integration activity will involve a GEO platform. Figure 4.2-3 shows the platform in place on a ballute OTV, aboard the Space Station. The shaped brake and lifting brake OTV's are also shown attached to a GEO platform, illustrating the differences in orientation required. The arrangements are dictated by engine thrust vector and physical interference requirements. Note that one of the Station RCS thrusters is pointed at the platform, and will have to be inhibited during mating operations.

### 4.2.2 Launch and Retrieval

#### 4.2.2.1 Proximity Operations Groundrules

Launching and retrieving spacecraft from the Space Station must satisfy the proximity operations ground rules given in JSC-19371. These ground rules are summarized in table 4.2-2. In view of the ground rules and the continuing contamination concerns, the conclusion drawn is that hydrazine systems may not be used in the vicinity of the Space Station for OTV deployment and retrieval. It is understood that the OMV has a waiver from a restriction on the use of hydrazine near the station. As will be seen, the $GN_2$ system is more than adequate to accomplish launch and retrieval.

#### 4.2.2.2 Primary Options

The primary launch and retrieval options examined are shown in figure 4.2-4 and are:

1. utilizing the OMV, and
2. autonomously by the OTV using an added OMV-type $GN_2$ RCS.

**OMV Launch and Retrieval**

Figure 4.2-5 illustrates OMV placement on the OTV for the purpose of launch with the OTV fully fueled and a 20,000 lbm payload to be delivered to GEO and retrieval with the OTV empty and no payload. The OMV has been located such that the OMV/OTV/ payload center-of-gravity location remains within the $GN_2$ thruster span under both conditions. An additional grapple fixture is required for the OTV since both OMV attachment and OTV holding with the MRMS must be done simultaneously as shown in figure 4.2-4.

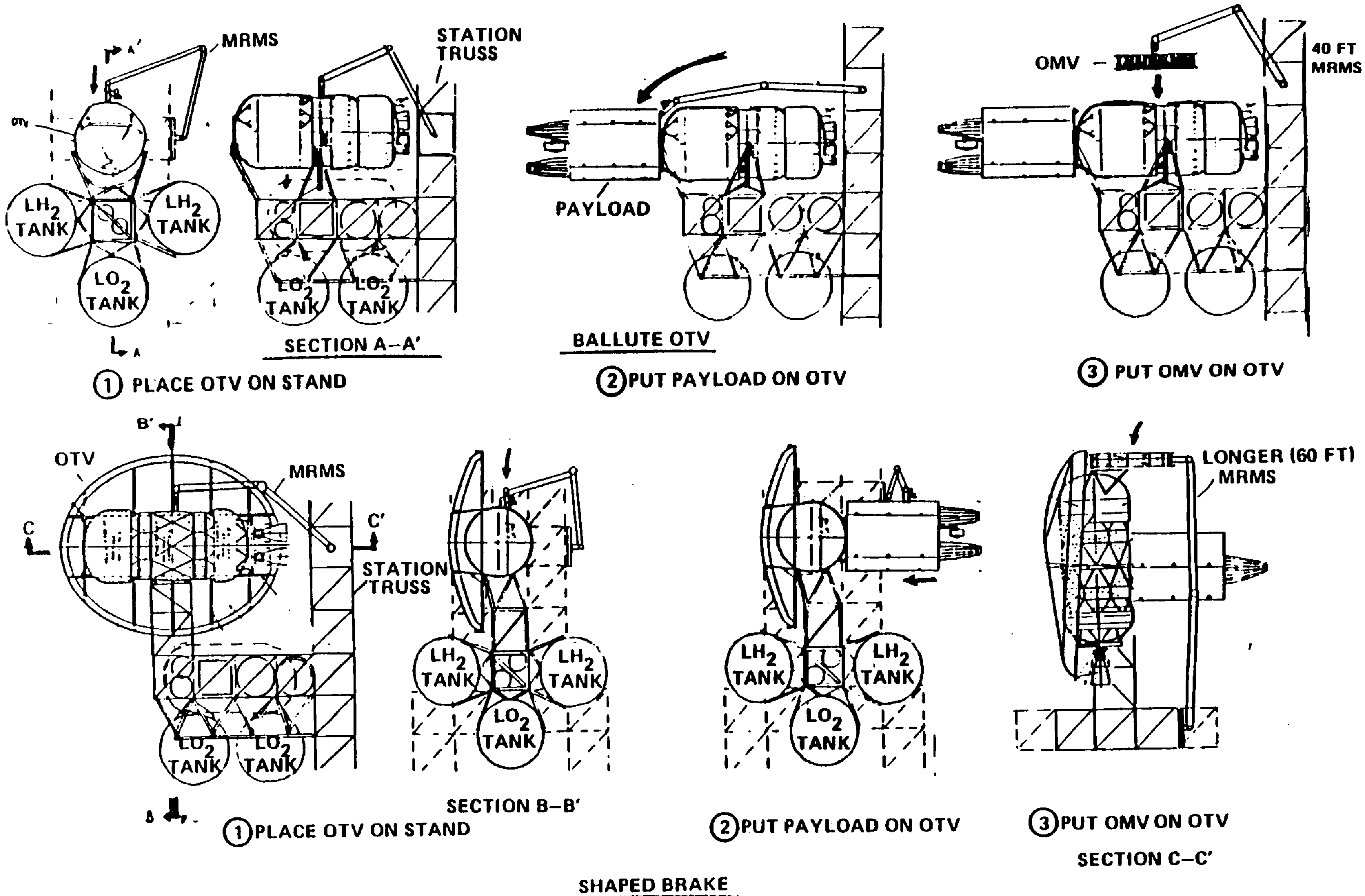



*Figure 4.2-2 OTV/Payload Mating*

OTV-808

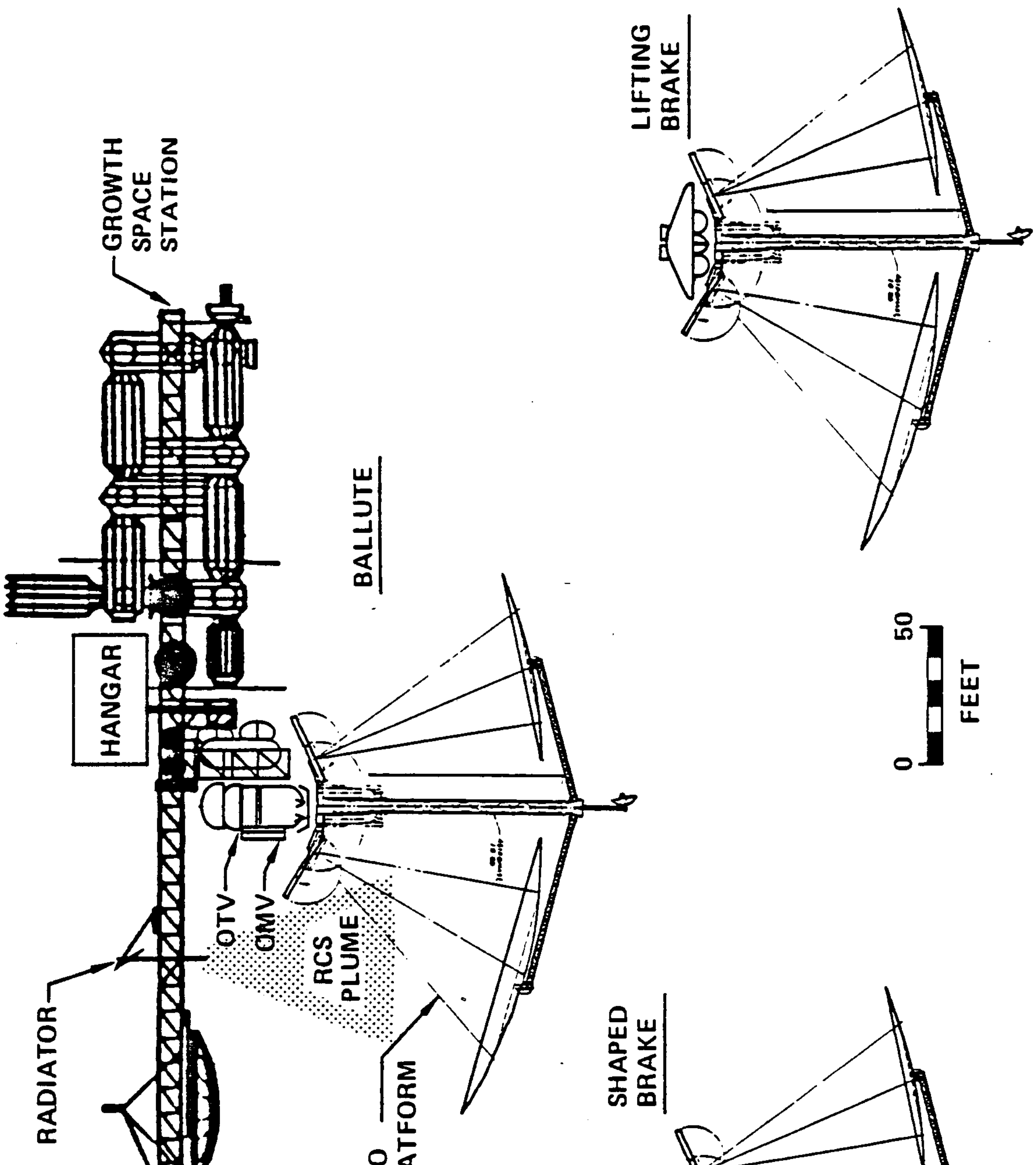
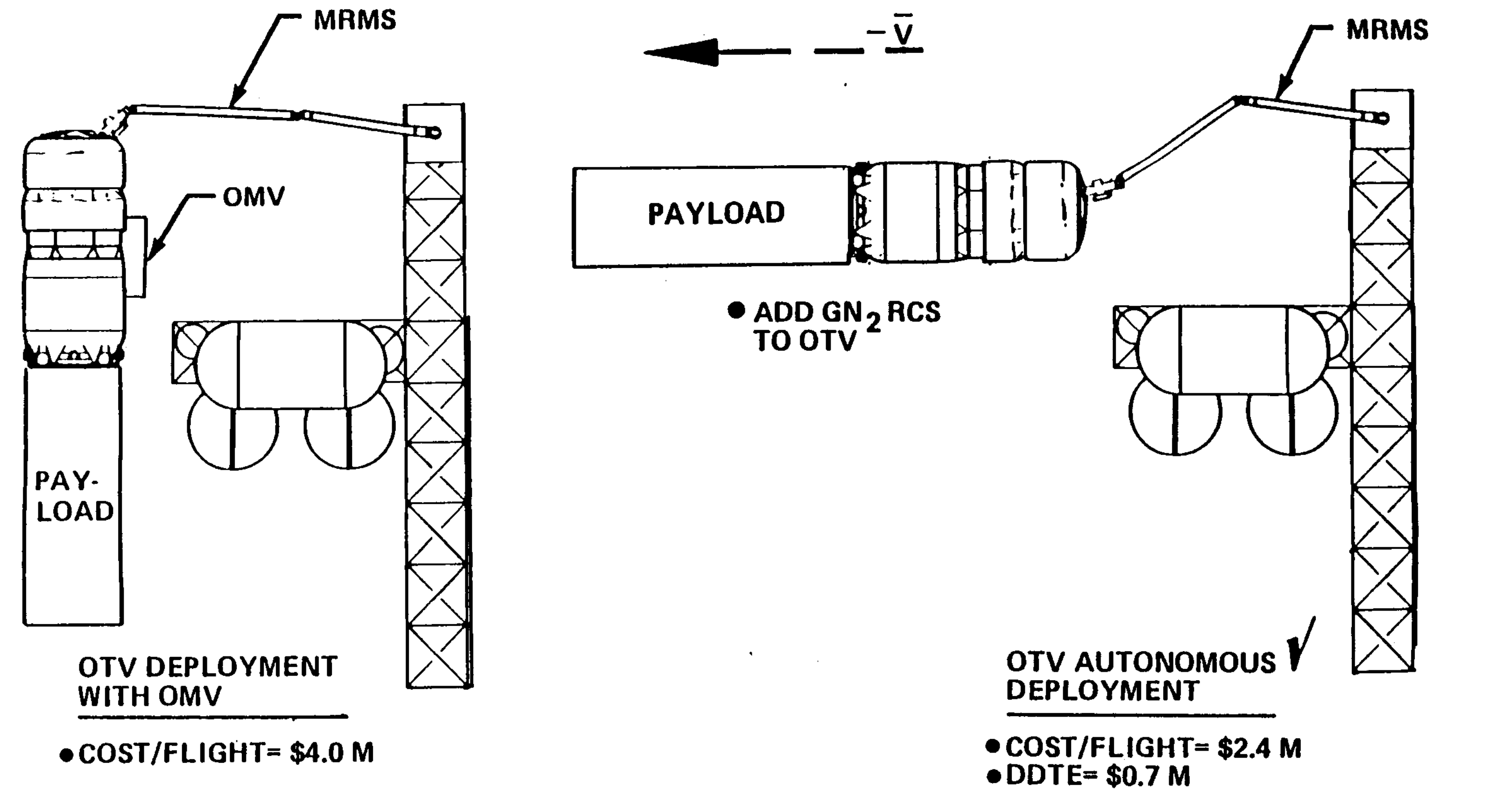



*Figure 4.2-3 GEO Platform — OTV Integration*

*Table 4.2-2 Proximity Operations Ground Rules (Source: JSC–19371)*

- DEPARTURE
  - MUST BE AT LEAST 10 NM FROM STATION FOR MAIN PROPULSION UNIT IGNITION
  - STATION CANNOT TRANSLATE FOR DOCKING
  - INITIAL SEPARATION $\Delta V = 0.2$ FT/SEC TO 180 FT
  - AFTER 180 FT ACCELERATE TO $\Delta V = 3$ FT/SEC
- RETURN
  - SAFE MAIN PROPULSION UNIT AT LEAST 8 NM FROM STATION
  - INITIATE PROX. OPS. AT 1000 FT FROM STATION
  - FINAL CLOSURE $\Delta V = 0.2$ FT/SEC
- INTERPRETATION
  - MAY NOT USE HYDRAZINE SYSTEMS FOR OTV DEPLOYMENT AND RETRIEVAL




- INITIAL POSITIONING WITH MRMS AFTER PAYLOAD MATING AND CHECKOUT
- DEPARTURE IN $-\bar{V}$ DIRECTION
- RETRIEVAL ACQUISITION EFFECTED BY MRMS

√ SELECTED

*Figure 4.2-4 OTV Deployment*

OTV-1208

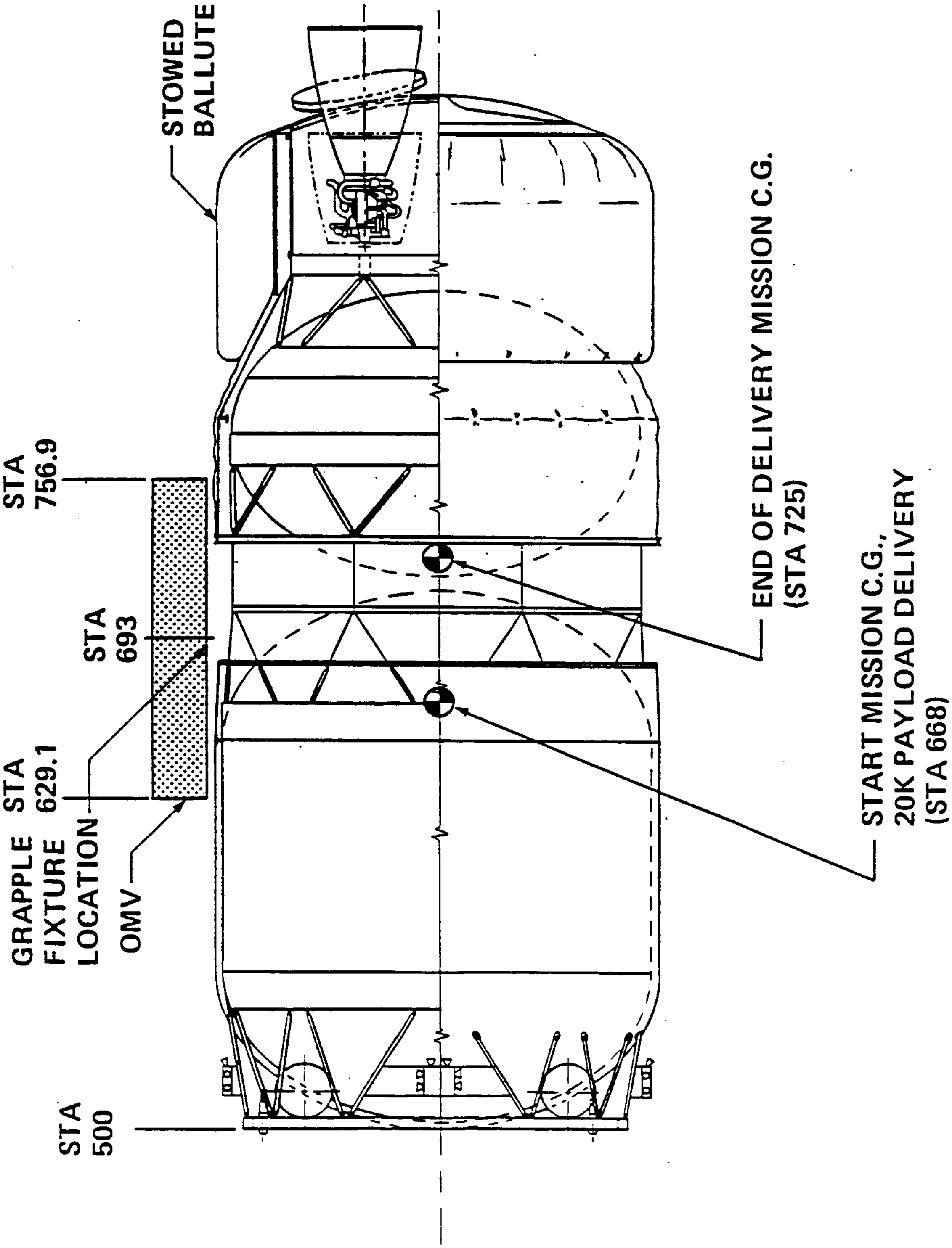



*Figure 4.2-5 OMV Location—SBOTV Deployment and Retrieval*

The $GN_2$ required by the OMV to accomplish the activities delineated in table 4.2-2 for both the launch and retrieval missions is 266 lbm. Refill of the OMV $GN_2$ tanks is assumed between launch and retrieval.

**Autonomous OTV Launch and Retrieval**

Launch and retrieval of the OTV using an on-board $GN_2$ system derived from the OMV $GN_2$ is depicted on the right side of figure 4.2-4. The requirements for this system in terms of delta-V, $GN_2$ usage, tank sizing, and weight summary are shown in table 4.2-3. Note that the total $GN_2$ used for launch and retrieval is 166 lbm for the OTV autonomous approach whereas, with OMV deployment, the total was 266 lbm. This difference is due to two factors: (1) without the OMV the mass to be accelerated is less, and (2) for OMV deployment and retrieval there are two round trip but only one for the autonomous OTV case.

**Cost Comparison**

The manhours required for OMV launch and retrieval are shown in table 4.2-4. Utilizing these manhours and the following charges (Phase II groundrules):

IVA — $18,000/HR

EVA — $148,000/HR

the preparation, mating, launch, inspection, and refurbishment cost per OTV mission is $3.475 million. At $1500/lbm delivered, the $GN_2$ cost is $399,000. Assuming a flight time for launch and retrieval of 3.5 hrs each, the IVA monitoring cost is $126,000. Therefore, the total cost to launch and retrieve the OTV using the OMV is $4 million.

All of the costs involved with OTV launch and retrieval are recurring. However, the addition of the $GN_2$ system and the impact of this additional mass on the $LO_2$ and $LH_2$ tank sizing, results in a DDT&E cost impact as well as recurring costs. The increase in $LO_2/LH_2$ requirements is 1883 lbm and a tank mass increase at 109.2 lbm. The estimated cost increases to design and manufacture the larger tanks are $0.260 million and $0.150 million, respectively. Recurring costs are: delivery of the added $LO_2/LH_2$, $2.049 million (at $1088/lbm); 166 lbm $GN_2$ delivery, $0.248 million; and 3.5 hrs IVA, $0.063 million.

The costs for each of the OTV launch and retrieval options are summarized in table 4.2-5. At the bottom of this table the costs are compared. It is seen that it costs $1.64 million more per flight to use the OMV than for an autonomous OTV. This amounts to a $221.4 million differential for the projected 135 flights. When the DDT&E cost is subtracted, the difference is LCC over the program is $220.7 million.

*Table 4.2-3 OTV $GN_2$ System Requirements*

DEPLOYMENT

- $\Delta V$ = 3 FT/SEC
- WEIGHT = 94,140 LBM (SBOTV + 20K LBM PAYLOAD)
- IMPULSE = 8,778 LBF-SEC
- $GN_2$ REQUIRED = 146.3 LBM (ISP = 60 LBF-SEC/LBM)

RETRIEVAL

- $\Delta V$ = 0.4 FT/SEC (ACCELERATE TO 0.2 FT/SEC AND STOP)
- $GN_2$ REQUIRED = 19.5 LBM

TOTAL $GN_2$ REQUIREMENT

- $GN_2$ = (146.3 + 19.5) = 165.8 LBM

$GN_2$ TANK SIZING

ADDING 20% for CONTINGENCIES AND 20 LBM HYDRAZINE SYSTEM PRESSURANT = 220 LBM

SELECTING 4–22" DIAMETER TANKS (HOLDS 243.5 LBM USABLE $GN_2$ AT 4,000 PSI AND FITS IN AVAILABLE VOLUME)

WEIGHT SUMMARY (LBM):

| | |
|---|---|
| 4 TANKS | 306.0 |
| 16 DUAL VALVE THRUSTERS | 24.0 |
| CONTROLS & INSTRUMENTATION | 13.7 |
| PLUMBING | 24.0 |
| TOTAL(DRY) | 367.7 LBM |
| TOTAL (WITH $GN_2$) = | 611.2 LBM |



OTV-1107

*Table 4.2-4 OMV Manhours Required for OTV Launch and Retrieval*

| TASK | OMV MANHOURS | | | |
|---|---|---|---|---|
| | LAUNCH | | RETRIEVAL | |
| | IVA | EVA | IVA | EVA |
| •PRIOR TO OTV LAUNCH/RETRIEVAL | | | | |
| • OMV LAUNCH PREPARATION | 2 | — | 2 | — |
| • OMV/OTV MATING | 6 | 6 | — | — |
| • LAUNCH COUNTDOWN | 1 | — | 1 | — |
| •AFTER OTV LAUNCH/RETRIEVAL | | | | |
| • OMV INSPECTION | 1 | 2 | 1 | 2 |
| • OMV REFURBISH | 2 | 2 | 2 | 2 |
| • OMV/OTV DEMATE | — | — | 6 | 6 |
| SUBTOTALS | 12 | 10 | 12 | 10 |
| TOTAL IVA TIME IS 24 HOURS | | | | |
| TOTAL EVA TIME IS 20 HOURS | | | | |

**Conclusion**

As a result of the analysis conducted, it is concluded that, on the basis of least LCC the preferred approach for launch and retrieval of the OTV is with an autonomous $GN_2$ RCS.

### 4.2.2.3 Alternate Launch and Retrieval Option

An alternate launch and retrieval concept that takes advantage of orbit mechanics has been given a preliminary evaluation. This approach is presented here to encourage a detailed evaluation. It is not felt that the current stage of analysis warrants an LCC comparison with the two approaches previously presented.

This approach uses the MRMS to initially deploy and retrieve the OTV and depends on orbit mechanics to provide the necessary separation or closure distance relative to the station. During retrieval a navigation accuracy of 20 feet or less is required to enable the MRMS to capture the OTV. This requires a laser ranging system. Figure 4.2-6 shows how this approach and rendezvous concept would work. Two laser distance measuring instruments (DMI) are located on the Space Station and reflectors are mounted on the OTV. At a distance of 5 nm, the DMI's acquire the vehicle and repeatedly measure the vehicle's position for 30 seconds to determine the vehicle's velocity and position to better than 0.01 ft/sec and 0.04 ft, respectively. By this method the OTV motion relative to the Space Station can be predicted and any corrective RCS burns made. This process is repeated as necessary until the last update is made within 2000 feet. Because of the shorter range and longer integration time, the position and velocity errors at the last update are 0.02 ft and 0.002 ft/sec. Figure 4.2-7 illustrates the relative motion of the OTV with respect to the Space Station in the capture vicinity. The three sigma error in maneuvering is much smaller than the reach of the Mobile RMS on the Station. If the capture is not made in the twelve minutes available, the OTV will move safely away from the Space Station for another attempt. The advantage of this type of maneuver is no RCS is needed within 500 ft the Station.

### 4.2.3 Servicing Via Automation

Because of the high cost of using Space Station crew, there is a desire to use automation to reduce overall servicing costs. Automation is applicable to tasks that are hazardous (such as fuel transfer), repetitive, uninteresting (inspection of vehicle), or require precision, speed, or strength not available from humans.

Our analysis focused on identifying potential OTV servicing tasks that could be done via automation and making an assessment regarding their likelihood considering such factors as frequency, dexterity, and intelligence level. The results of this analysis is

*Table 4.2-5 SBOTV Launch and Retrieval OMV Use Versus OTV Autonomy*

**RECURRING COSTS PER FLIGHT:**

| OMV LAUNCH & RETRIEVAL | | AUTONOMOUS OTV | |
|---|---|---|---|
| PREP., MATING, LAUNCH, INSPECTION & REFURB. | $3.475M | • $LO_2/LH_2$ DELIVERY (1883 LBM) | $2.049M |
| • $GN_2$ DELIVERY (266 LBM) | $0.399M | • $GN_2$ DELIVERY (165.8 LBM)** | $0.248M |
| • FLIGHT OPERATIONS (7.0 HOURS IVA) | $0.126M | • IVA (3.5 HOURS) | $0.063M |
| TOTAL | $4.000M | TOTAL | $2.360M |

**ADDED DDT&E COSTS:**

| OMV LAUNCH & RETRIEVAL | | AUTONOMOUS OTV | |
|---|---|---|---|
| NONE* | | • $GN_2$ RCS *** | |
| | | • DESIGN | $0.100M |
| | | • MANUFACTURE | $0.200M |
| | | • ENLARGED CRYO TANKS DELTA | |
| | | • DESIGN | $0.260M |
| | | • MANUFACTURE | $0.150M |
| | | TOTAL | $0.710M |

**LCC COMPARISON:**

- COST PER FLIGHT DIFFERENCE: $4.000 - $2.360M = 1.640/FLIGHT
- OVER THE PROJECTED NUMBER OF FLIGHTS: $1.640 X 135 = $221.4M
- TOTAL LCC Δ IS $220.7M

**CONCLUSION: LAUNCH AND RETRIEVE SBOTV USING AUTONOMOUS OTV SYSTEM**

*DOES NOT INCLUDE COST OF ADDING A SECOND GRAPPLE FIXTURE TO OTV FOR MRMS, IF REQUIRED

**USUAL REQUIREMENT WILL NOT INCLUDE CONTINGENCY $GN_2$. HYDRAZINE PRESSURANT REQUIREMENT NOT CHARGED AGAINST THE $GN_2$ SYSTEM FOR THIS TRADE.

***THE OTV $GN_2$ SYSTEM IS IDENTICAL TO THE OMV SYSTEM EXCEPT FOR TANK SIZES AND PLUMBING ROUTING; ∴ SMALL DDT & E COST



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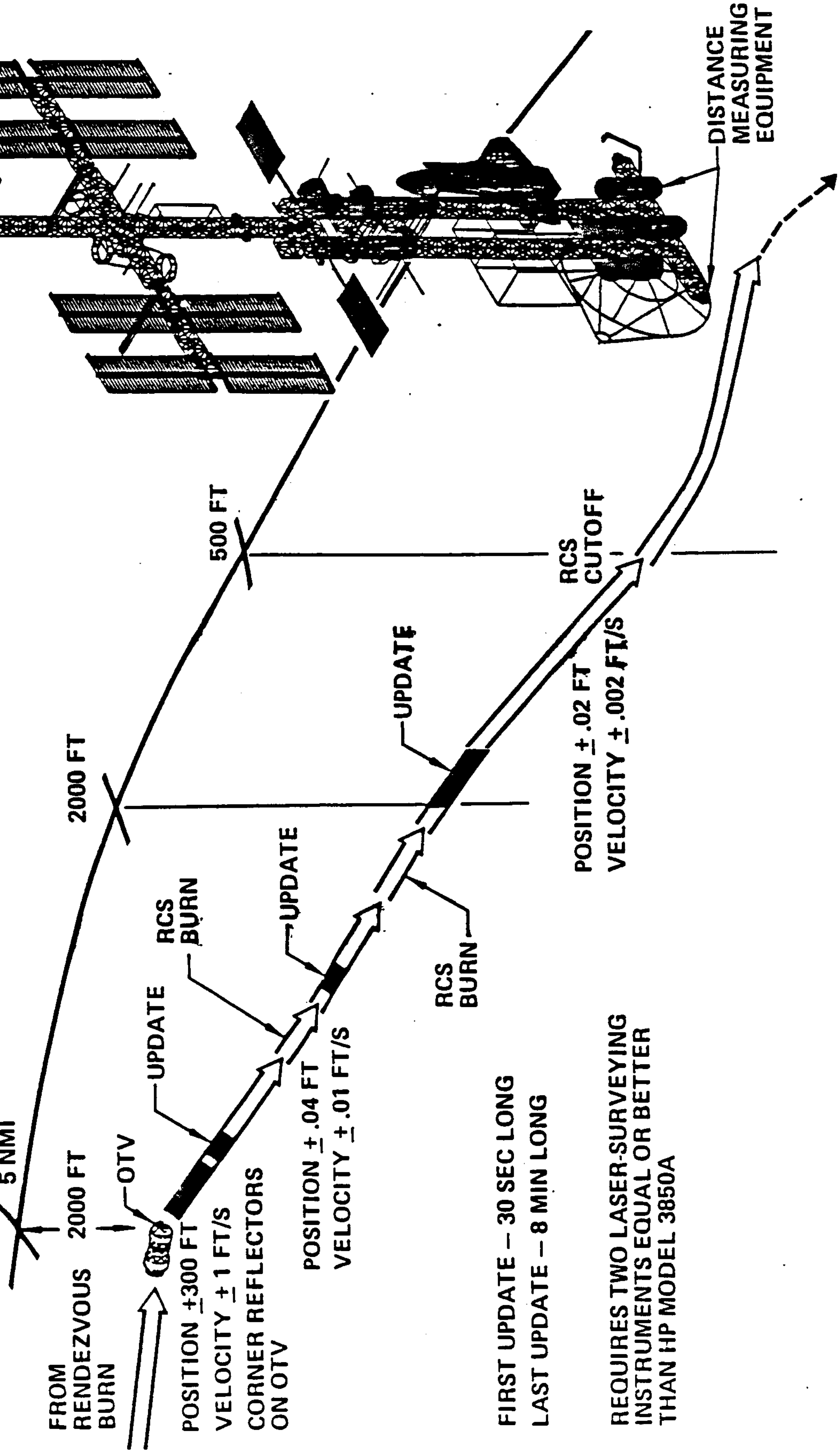


*Figure 4.2-6 Approach and Rendezvous Concept*

APPROACH ORBIT (RELATIVE TO STATION C.G.)

| | |
|---|---|
| STARTING POSITION: | 2000 FT BEHIND |
| | 720 FT BELOW |
| PERIGEE: | 720 FT BELOW |
| APOGEE: | 120 FT BELOW |
| TIME: | -47 MINUTES |

MANEUVERS

| | |
|---|---|
| DISTANCE MEASUREMENT | -45 MIN |
| RCS | -44 MIN |
| DISTANCE MEASUREMENT | -43 MIN |
| DISTANCE MEASUREMENT | -32 TO -24 MIN |
| FINAL RCS | -23 MIN (500 FT) |

ERRORS

NAVIGATION 1 $\sigma$ = 9 INCHES @ CAPTURE
RCS CONTROL 1 $\sigma$ = 4 INCHES @ CAPTURE

VELOCITY AT CAPTURE: 0.06 FT/SEC

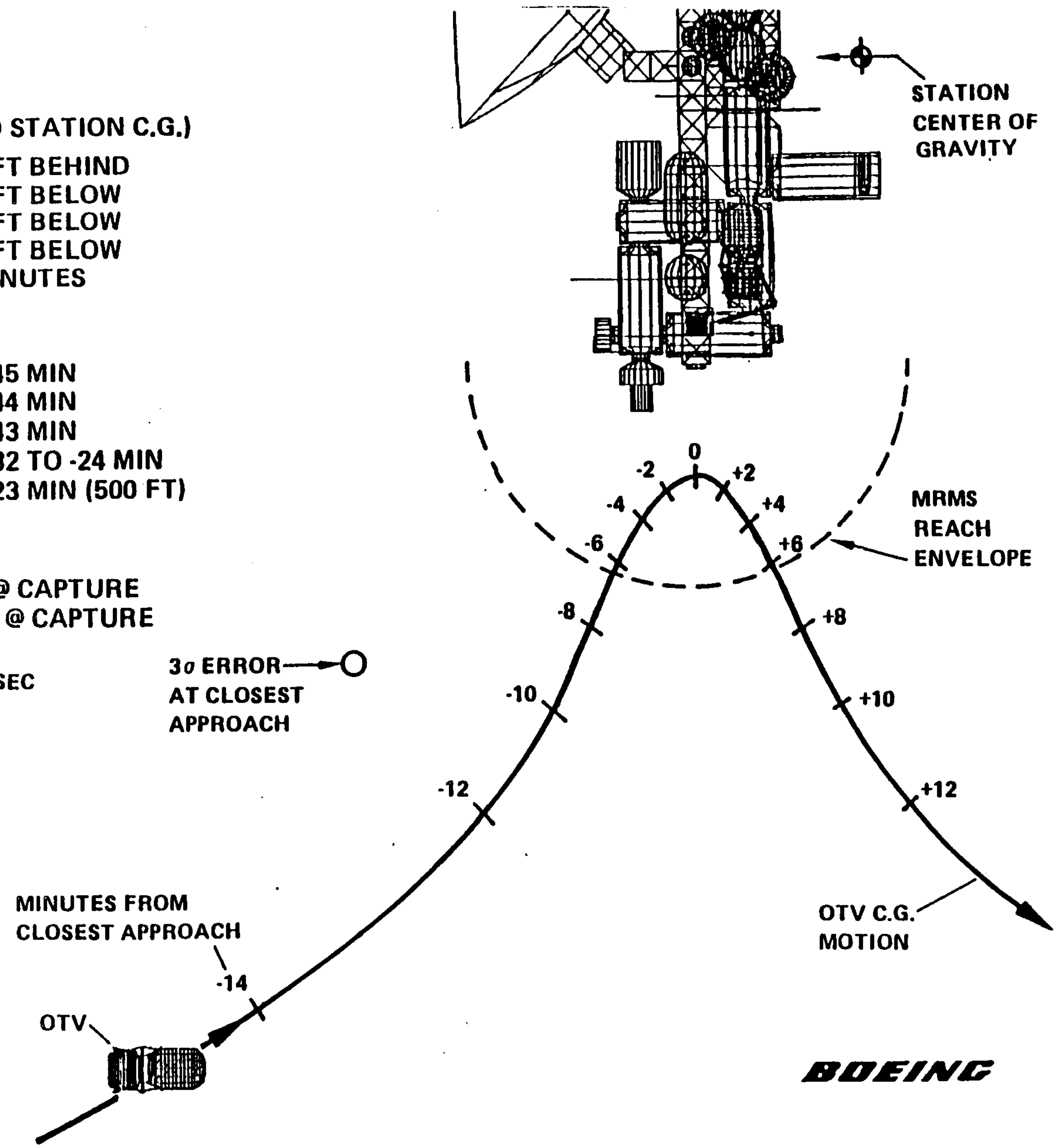


*Figure 4.2-7 Orbit Mechanics Recovery Technique*

shown in Table 4.2-6. It will be noted that a number of tasks appear to be legitimate candidates. Others are viewed as not being good candidates because of having a low frequency or the level of difficulty is too high. Finally, there are a few that require more analysis before a preliminary decision is made.

The final decision on automating a given task however will be highly influenced by cost. Estimating the cost savings resulting from reduced crew servicing operations is straight forward. Much more difficult, however, is estimating the software cost to implement the task since the task itself and equipment involved are not well defined, identifying the cost of the robotic equipment to perform some of the automation, and finally estimating the cost associated with maintenance on the automation equipment.

In summary, the potential for automation in servicing is high. However, due to the uncertainty in the cost to achieve automation for on-orbit servicing our baseline approach is to use the crew to perform many of the servicing tasks such as removal and replacement of all OTV ORU's. It is recommended however that this area be reexamined when the Space Station automation studies become available.

Table 4.2-6 *Automation Analysis – On-Orbit Servicing*

| POTENTIAL TASKS | FREQUENCY/ MISSION | DEXTERITY EQUIVALENT | INTELLIGENCE LEVEL | GOOD CANDIDATE FOR AUTOMATION? |
|---|---|---|---|---|
| • TRANSFER HARDWARE ELEMENT FROM ONE LOCATION TO ANOTHER ON STATION | ~6 | 6 DOF* | COLLISION AVOIDANCE | YES, HARD BUT FREQUENT ENOUGH TO WARRANT AUTOMATING |
| • CONNECT/DISCONNECT UMBILICALS | 3 | 1 DOF | PREPROGRAMMED | YES |
| • TRANSFER PROPELLANTS FROM ONE TANK TO ANOTHER | 2 | 1 DOF | OUT OF LIMIT SENSING | YES |
| • INTEGRATE VEHICLE STAGE(S) AND PAYLOAD | 1 | 6 DOF | ALIGNMENT AND SENSING | NO, REQUIRES SENSITIVITY & HAND-EYE COORDINATION |
| • PRELAUNCH CHECKOUT | 1 | —NONE— | OUT OF LIMIT SENSING | YES |
| • POSTFLIGHT INSPECTION | 1 | 3 DOF | DAMAGE DETECTION | YES |
| • REPLACE RCS CLUSTER | 0.53 | HUMAN HAND | PREPROGRAMMED | MORE ANALYSIS REQUIRED |
| • REPLACE FUEL CELL | 0.27 | HUMAN HAND | PREPROGRAMMED | MORE ANALYSIS REQUIRED |
| • REPLACE ENGINE & VALVES | 0.11 | HUMAN HAND | PREPROGRAMMED | NO, TOO HARD |
| • REPLACE AVIONICS BOX | 0.18 | 3 DOF | PREPROGRAMMED | YES |
| • REPLACE UTILITY BATTERY | 0.006 | 3 DOF | PREPROGRAMMED | NO, TOO INFREQUENT |
| • REPLACE EPS PUMP | 0.003 | HUMAN HAND | PREPROGRAMMED | NO, TOO INFREQUENT |
| REPLACE EPS ACCUMULATOR | 0.002 | HUMAN HAND | PREPROGRAMMED | NO, TOO INFREQUENT |

*DEGREE OF FREEDOM

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# 5.0 OTV IMPOSED REQUIREMENTS

This section summarizes the requirements and needs imposed by an OTV when it is to have an interface with the Space Station. Data is presented for all those space based concepts as well as the ground based concept.

## 5.1 SPACE BASED OTV

### Crew Requirements

Accommodation installation and turnaround operations times required for the OTV's are presented in table 5.1-1. The shaped brake OTV took the longest primarily because it required the largest hangar. Assuming an EVA shift of 6 working hours/day, 6 days/week, and a crew of three required during EVA (2 outside, one inside), total installation times of seven to ten weeks are required for space based OTVs. Ground based OTV's are estimated to take only one and one half weeks because the hangar is smaller and less internal equipment is required.

When viewed from an annual operational basis (OTV turnaround—maintenance and servicing), the crew requirement average is only 0.5.

### Power Requirements

Power requirements are summarized in table 5.1-2. The principal power requirement for a space-based OTV is for the propellant transfer pumps associated with compressing the gases resulting from line and OTV chilldown. Based on a seven hour transfer time to unload a tanker or an OTV, the estimated power required is 20 kw.

The average total power level is very dependent on the OTV thermal control requirements while it is in the hangar, which is the majority of the time. The total average power is estimated at 480 watts.

### Accommodation Size and Weight

A summary of the weights and size associated with all of the ballute braked OTV accommodations required at the station is presented in table 5.1-3. A more detailed breakdown of the support equipment as well as installation times is shown in table 5.1-4.

### Delivery Requirements

Table 5.1-5 summarizes the non-recurring and recurring delivery requirements for the various OTV configurations expressed in terms of STS launches required. These

*Table 5.1-1 Space Station Crew Requirements for OTV Support*

| ACCOMMODATIONS INSTALLATION TIME | | | | |
|---|---|---|---|---|
| ACCOMMODATIONS ELEMENT | OTV CONFIGURATION | | | |
| | BALLUTE | SHAPED BRAKE | LIFTING BRAKE | GROUND-BASED [1] |
| HANGARS (2) | 120 | 220 | 160 | 40 |
| STORAGE TANKS (2 SETS) | 40 | 40 | 40 | — |
| ROBOT TRACKS | 30 | 30 | 30 | — |
| ROBOTS (4) | 8 | 8 | 8 | — |
| FIXED LIGHTS | 30 | 30 | 30 | — |
| TEST EQUIPMENT | 6 | 6 | 6 | 6 |
| STATION INTERFACE | 6 | 6 | 6 | 6 |
| OTHER TOOLS | 10.5 | 9.5 | 9.5 | 3 |
| ENGINE STORAGE | 2 | 2 | 2 | — |
| LRU STORAGE | 3 | 3 | 3 | — |
| BALLUTE STORAGE (2 SETS) | 4 | — | — | — |
| LIFTING BRAKE STORAGE | — | — | 3 | — |
| TOTAL INSTALLATION TIME (HOURS EVA) | 259.5 | 354.5 | 297.5 | 55.0 |

[1] ACCOMMODATIONS FOR PAYLOAD/ AUXILIARY TANK/MAIN STAGE MATING AND CHECKOUT ONLY

- CREW REQUIREMENTS – 6 HR EVA SHIFT/6 DAY WEEK
  10 HR IVA SHIFT/6 DAY WEEK
  - INSTALLATION (CREW OF 3)
    BALLUTE – 7.2 WEEKS
    SHAPED BRAKE – 9.8 WEEKS
    LIFTING BRAKE – 8.3 WEEKS
    GROUND BASED – 1.5 WEEKS
  - OPERATIONS (@ 8 FLIGHTS/YEAR)
    160 CREW–DAYS/YEAR = 0.5 CREW AVERAGE



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*Table 5.1-2. OTV Power Requirements at Space Station*

- SPACE-BASED OTV

| ACCOMMODATIONS EQUIPMENT | POWER REQUIRED (W) | USAGE/ MISSION (HR) | ENERGY/ MISSION (KWH) |
|---|---|---|---|
| PROPELLANT TRANSFER | 20,000 | 16 | 320.0 |
| OTV THERMAL CONTROL | 100 | 1080 | 108.0 |
| HANGAR LIGHTING | 1,500 | 40 | 60.0 |
| MOBILE ROBOT | 200 | 80 | 16.0 |
| WORK LIGHT | 100 | 60 | 6.0 |
| CAMERA | 100 | 40 | 4.0 |
| MRMS | 500 | 6 | 3.0 |
| INSPECTION & TEST EQUIPMENT | 500 | 6 | 3.0 |
| DOOR & LATCH MECHANICAL | 150 | 2 | 0.3 |
| TOTAL | -- | -- | 520.3 |

- PEAK POWER—20KW
- AVERAGE POWER—480W
  (AT 8 FLIGHTS/YEAR)

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*Table 5.1-3 Size and Weight Requirements for OTV Accomodations*

**SPACE BASED OTV — BALLUTE BRAKE**

| ACCOMMODATIONS ELEMENT | SIZE (FT) | WEIGHT (LB) |
|---|---|---|
| • STATION ADDITIONS & MODIFICATIONS | | |
| • TRUSS STRUCTURE | 9 x 9 x 36 | 288 |
| • OTV & STORAGE TANK ATTACHMENTS | —NA— | 700 |
| • ELECTRIC DISTRIBUTION EXTENSION | —NA— | 150 |
| • HANGAR 1 (SERVICING) | 31 x 31 x 55 | 5,250 |
| • SUPPORT EQUIPMENT & SUPPLIES | —NA— | 5,500 |
| • HANGAR 2 (STORAGE) | 19 x 19 x 42 | 2,500 |
| • PROPELLANT STORAGE (2 SETS) | | |
| • $LH_2$ TANKS | 13 x 13 x 29 EACH | 37,944 (11372 DRY) |
| • LOX TANKS | 13 x 13 x 13 EACH | 163,554 ( 4126 DRY) |
| • PROPELLANT TRANSFER SYSTEM | 9 x 9 x 36 | |
| • PUMPS | —NA— | TBD |
| • GASEOUS STORAGE TANKS | —NA— | TBD |
| • COMMON MODULE PROVISIONS | | |
| • AIRLOCK | 5 x 5 x 7 | 1,000 |
| • CONTROL CONSOLE | 5 x 5 x 2 | 400 |
| TOTAL | —NA— | 220,165 + TBD |



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*Table 5.1-4 Accommodations Hardware and Supplies – One Set*

| ELEMENT 2 | WEIGHT (LB) | SIZE (FT) 1 | INSTALLATION TIME (EVA HOURS) |
|---|---|---|---|
| HANGAR–BALLUTE | 5250 | 0.7 FLIGHTS | 60 |
| HANGAR–LIFTING BRAKE | 7250 | 1.0 FLIGHTS | 80 |
| HANGAR–SHAPED BRAKE | 8975 | 1.2 FLIGHTS | 110 |
| STORAGE–AUXILIARY TANK | 2150 | 0.3 FLIGHTS | 20 |
| PROPELLANT STORAGE TANK SET | 15498 | 1 FLIGHT | 20 |
| PROPELLANT TRANSFER SYSTEM | TBD | | |
| STATION INTERFACE | 200 | 2 x 2 x 10 | 6 |
| ROBOT (EACH) | 500 | 3 x 3 x 2 | 2 |
| END EFFECTOR | 30 | 1.5 D x 2 L | 0.5 |
| FOOT RESTRAINT | 30 | 1 x 1 x 5 | 0.5 |
| TRACKWAY | 460 – 780 | 100–200 CU FT | 30 |
| LIGHTS (FIXED) | 250 | 4 x 3 x 16 | 30 |
| LIGHT (MOVEABLE) | 20 | 1 x 1 x 1 | 0.5 |
| BALLUTE TOOL | 200 | 10 D x 1 L RING | 1.0 |
| ENGINE TOOL | 100 | 3 x 3 x 7 | 1.0 |
| CAMERA | 20 | 1 x 1 x 2 | 0.5 |
| TEST EQUIPMENT | 500 | 2 x 2 x 5 | 6 |
| MINOR TOOLS | 600 | 2 x 4 x 6 | 3 |
| LRU SET | 600 | 3 x 8 x 10 | 3 |
| ENGINE SET | 800 | 5 x 10 x 10 | 2 |
| BALLUTE | 1200 | 8 L x 15 D CYL | 2 |
| LIFTING BRAKE PACKAGE | 1200 | 5 x 13 x 4 | 3 |

1 PACKAGED FOR LAUNCH    2 QUANTITY ONE SET

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*Table 5.1-5 Delivery Requirements*

• NON-RECURRING DELIVERY — STS FLIGHTS

| ACCOMMODATIONS ELEMENT | OTV CONFIGURATION | | | |
|---|---|---|---|---|
| | BALLUTE | SHAPED BRAKE | LIFTING BRAKE | GROUND-BASED |
| HANGARS (2) | 1.40 | 2.40 | 2.00 | 0.60 |
| PROPELLANT STORAGE (2 SETS) | 2.00 | 2.00 | 2.00 | --- |
| INITIAL SPARES | 0.15 | 0.15 | 0.15 | 0.01 |
| BALLUTE (1) | 0.13 | --- | --- | --- |
| LIFTING BRAKE TPS (1 SET) | --- | --- | 0.05 | --- |
| HANGAR EQUIPMENT (2 SETS) | 0.20 | 0.24 | 0.22 | 0.02 |
| TOOLS (2 SETS) | 0.05 | 0.05 | 0.05 | 0.02 |
| TOTALS | 3.93 | 4.84 | 4.47 | 0.65 |

• RECURRING DELIVERY (PER YEAR)

| | | | | |
|---|---|---|---|---|
| TOOLS AND EQUIPMENT | 0.01 | 0.01 | 0.01 | --- |
| PROPELLANT STORAGE | 0.02 | 0.02 | 0.02 | --- |
| TOTALS | 0.03 | 0.03 | 0.03 | --- |

numbers refer only to the accommodations elements and do not include delivering the OTV itself.

## 5.2 GROUND BASED OTV

The ground-based OTV needs are shown in table 5.2-1. As indicated the requirements are much less than for a space based OTV, because only a small storage hangar is required and only physical integration of the OTV and auxiliary tank/payload is necessary for a ground based OTV.

Most services were reduced by approximately a factor of six, while power requirements are negligible.

## 5.3 SUMMARY

A summary of the major requirements imposed by the OTV are presented in table 5.3-1. Delivery needs cover all support hardware required by an OTV including hangars, support equipment, propellant storage systems, and hardware modifications to the basic Station. Crew support in terms of installation relate to the activity involved in assembly and integration of the accommodations hardware at the Station. The operations aspect deals with the time required to prepare a given OTV for each flight. The value indicated is a time smeared average crew size although when the turnaround operations are actually performed a total of three people are involved (two EVA and one IVA).

The peak power demands for SB OTV's relate to the refueling operations and the average relates to maintenance and storage considerations. Perhaps the biggest impact on the Station for the SB OTV is the weight that is added. With inclusion of two OTV's the weight approaches 250,000 lbs.

*Table 5.2-1 Ground-Based OTV Space Station Requirements*

| | GROUND BASED OTV – BALLUTE | PERCENT OF SPACE-BASED OTV (BALLUTE) REQUIREMENT |
|---|---|---|
| • **DELIVERY:** | 0.65 STS FLIGHTS | 16.5% |
| • **CREW:** | | |
| • INSTALLATION: | 55 EVA HOURS | 21.4% |
| • OPERATIONS: | 24 CREW-DAYS | 15.0% |
| • **POWER:** | 6.4W AVERAGE | 1.3% |
| | 1050W PEAK | 5.3% |
| • **SIZE & WEIGHT:** | | |
| • SIZE (HANGAR) | 23 x 23 x 22 FT | 22% |
| • WEIGHT | 4000 DRY | 11.7% |
| | (32,000 WITH AUXILIARY TANK) | 14.5% |

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*Table 5.3-1 OTV Station Accommodations Imposed Requirements*

| REQUIREMENT | GBOTV BALLUTE | SB OTV BALLUTE | SB OTV LIFTING | SB OTV SHAPED |
|---|---|---|---|---|
| ● DELIVERY (STS FLIGHTS) | 0.65 | 3.9 | 4.5 | 4.9 |
| ● CREW SUPPORT [1] | | | | |
| • INSTALLATION (WEEKS) | 1.5 | 7.2 | 8.3 | 9.8 |
| • OPERATIONS (AVG USE) | 0.08 | 0.5 | 0.5 | 0.5 |
| ● POWER: AVERAGE (KW) | 0.01 | 0.5 | 0.5 | 0.5 |
| PEAK (KW) | 1 | 20 | 20 | 20 |
| ● PHYSICAL | | | | |
| • HANGAR SIZE (FT.) | 23x23x22 | 55x55x31 | 50x50x37 | 50x54x36 |
| • WEIGHT (KLBS) | 4 | 220 | 222 | 224 |

[1] 3 PEOPLE (2 EVA, 1 IVA)

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## 6.0 ACCOMMODATIONS ISSUES

There are a number of open issues in the accommodations area that should be further addressed through a joint effort by the space station and OTV programs.

Accommodation of the propellant storage tanks is a major issue relative to station dynamics and controllability. Since the tanks are frequently partially empty slosh becomes a possibility. Should this prove to be a legitimate problem consideration should be given to benefits of slosh baffling, smaller but more numerous tanks or even another assessment of a separate platform.

The impact on the station micro-gravity level is also a concern considering the large masses of a fueled OTV with large payload and the propellant storage tanks. For example, a $10^{-6}$ gravity tolerance requires the center of gravity to move no more than 2.5 meters in the vertical direction. An object that is 10% of the Station mass, such as a fueled OTV with payload, would be constrained to operate within 25 meters (82 feet) of the Station center of gravity (CG). The propellant storage tanks would comprise as much as 20% of the Station mass, and would therefore have to be located within 41 feet of the CG.

Use of a cold gas $N_2$ system on the OTV for launch and retrieval has minimized the impact on station contamination. Preliminary data however indicates that both the station RCS and Orbiter RCS operations (during docking) exceed the contamination limits thereby bringing up the issue of common groundrules for all elements.

Several issues relate to OTV/payload integration. The 80,000 lbm lunar mission, which requires multiple stages, and a GEO platform that is deployed on the Space Station both require a larger volume than is available on the power tower Station design. The OTV and payload, especially a GEO platform, have a large mass and moment of inertia. The capability required of a Mobile RMS to move these objects, and the Station truss rigidity to make the movements controllable have not been determined.

While automation and teleoperation could potentially perform many of the OTV servicing operations, and save Station crew time, the total cost of automation has not been assessed. This is due to the immature state of this technology and the rapid pace of development.

Finally, we have assumed the use of the Space Shuttle in all our trade studies. A Shuttle Derivative Vehicle will have lower transportation costs per pound. This will affect the numerous trades that assume a dollars per pound value of delivery to orbit. In addition, the operational concept involving a Shuttle Derivative and OTV has to be developed. The implications of advanced launch systems is addressed in Volume IX.

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3. NASA Contractor Reports 3535 and 3536, Future Orbital Transfer Vehicle Technology Study, Boeing Aerospace Company, Contract NAS1-16088, May 1982.

4. Report No. GDC-SP-83-052, Definition of Technology Develoment Missions for Early Space Station, General Dynamics Convair Division, Contract NAS8-35039, June 1983.